UNDERWATER BIOACOUSTIC ANALYSIS OF BEARDED SEAL BEHAVIOR OFF BARROW, ALASKA.

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A

THESIS

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Abstract

Bearded seal vocalizations were collected incidentally during the 1993 bowhead whale census. Analysis of seal locations, calculated by triangulation of the vocalizations, provided information on seal swim velocity, distribution, and movement. Swim speeds fell within previously documented values. Seal positions, when correlated with satellite images, suggested that seal distribution was directly associated with ice topography. Individually tracked seals exhibited different types of movements including: maintenance of position, rapid increase in speed and slower, prolonged directional travel. Swim speeds, distributions, and movements suggest distinct behaviors which may include foraging, territorial or female defense, or display. Movement and behaviors may alter as ice conditions change throughout the breeding season. Bioacoustics, when coupled with other research methods, is a useful tool in the study of the behavior of less accessible animals.

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Preface

This thesis has been separated into chapters designed to stand alone, with the intent to publish Chapters 4 and 6. The general introduction, methods and summary chapters provide the reader of this thesis a more detailed and complete narrative of the study as a whole.

CHAPTER 1: INTRODUCTION

Alaskan living marine resources are rich and varied, ranging from invertebrates to fish, seals and whales. Marine mammals are especially and exclusively economically important to indigenous people. Subsistence hunting provides not only food for the Eskimo people, but also materials for clothing and boat and kayak manufacture, and for art, including carvings, scrimshaw and baleen. In order to insure continued use of marine mammals, current populations need to be assessed for proper conservation. A basic understanding of marine mammal ecology and behavior can aid in developing effective management techniques.

Marine mammal research involves various types of study, including population ecology, physiology, behavior and natural history. Population research has primarily utilized land-based and air census techniques. The problems associated with these current census methods include weather limitations, human error, and animal sightability. Physiological and behavioral research programs are often difficult and entail either hands-on work or long observational periods. Satellite and radio tagging are other important tools used in the study of individual movement and mother-pup attendance behavior, provided an animal is accessible for attachment and removal of the transmitter. Over all, these types of investigations provide a great deal of information on population size, distribution, and general health for those species accessible by land or fast ice. Unfortunately, these forms of research do not provide as much information on species that spend most or all of their time at sea or in pack ice. Whales, bearded seals (Erignathus barbatus), and to a lesser degree, walrus (Odobenus rosmarus), are among those less accessible. Bearded seals tend to prefer pack ice conditions and shallow waters of 200 meters or less (Burns, 1981). Natural history, much of which has been obtained from native hunts, has provided a great deal of information on most marine mammals including whales, walrus and bearded seals. However, more information is needed to develop proper conservation techniques.

Fortunately, these less accessible species have a characteristic that enables their study from shore: they are very vocal. Bioacoustic research offers new methods for studying their biology. For example, bowhead whale (Balaena mysticetus) census work began as a visual study in the mid-1970's and was later modified and improved by a combination of visual and acoustic observations beginning in 1984 (George et al., 1995). Studies of individual acoustic recognition in walrus, combined with visual observations, have been used to identify males during breeding season (Stirling, pers. comm.). Bearded seal research has also benefited by the availability of acoustic analysis in determining population size, distribution, migration routes and breeding behavior (Cleator et al 1989, Cleator & Stirling, 1990 and Budelsky 1992).

The bioacoustic study of marine mammals is based on passive acoustics (listening and recording sounds produced by the animal itself) and therefore is a non-invasive technique (Urick, 1983). This type of research allows animals to be studied without causing behavioral changes. In such studies, information is gathered by a hydrophone and sonobuoy system (Urick, 1983). Researchers can gather the information from kilometers away and minimize interaction.

Marine mammal vocalizations are complex and can be comprised of a variety of types. For example, whistles are pure tones with little or no harmonic structure. Calls (vocalizations containing harmonics) are complex structures, often consisting of several parts. Calls may be frequency-modulated (FM), or amplitude-modulated (AM). Songs are constructed from a series of calls. Clicks are very short pulses, contain high energy over a broad bandwidth, and are often repeated in "trains" with repetition rates of 1 - 300 clicks/sec. Marine mammals also produce auxiliary sounds including teeth chatter, fin/tail-slapping, bubble-blowing and ice-scraping.

Behaviors associated with vocalizations also vary from one species to another. Humpback whales (Megaptera novaeangliae) utilize long complex songs during breeding that may communicate breeding status (Payne, 1978). Bowhead whales produce both calls and songs as they migrate along the Alaska coast. The calls may coordinate herd movement by communicating ice conditions and direction of travel to others (Clark, Ellison, & Beeman, 1986). Specific calls used by the Antarctic Weddell seals (Leptonychotes weddellii) may advertise breeding condition, while others may be used to defend territory (Thomas, Zinnel & Ferm, 1983). Codas, clusters of clicks, are used by sperm whales (Physeter catodon), perhaps to communicate information of location, food resources, or overall condition (Watkins, et al. 1985). Dolphins may utilize signature whistles to identify each other (Caldwell, et. al., 1971). Research conducted on California sea lions (Zalopbus californianus) suggests that individual recognition occurs within species, as in mother-young interactions (Trillmich, 1981).

Bioacoustic research can take many forms. For example, location and movement can be studied to determine population size and distribution. A system in which the location of a vocalizing animal can be pinpointed requires at least three receivers, i.e., hydrophones. When the animal vocalizes, the signal will travel to the system and be received at each hydrophone at a given time. Triangulation of the position of an animal takes place by calculating the time differences of the signals received at each hydrophone. By observing swim speeds, consecutive locations can be used in tracking an animal and studying movement. This type of research has been used in bowhead whale census in Barrow since 1984 (George, et al., 1995) and in Budelsky's (1992) bearded seal research.

The purpose of this research thesis was to study the underwater bioacoustic behavior of bearded seals off Barrow, Alaska. I describe the movement of animals as well as spacing, local abundance and distribution. As stated above, this seal is a pagophilic species, i.e., associated with pack ice, and therefore very difficult to study. Most information on this species consists of natural history data gathered from Eskimo hunting. Bioacoustic research was begun on this species in 1987 by Cleator, in which late winter / early spring abundance and vocal attributes of seals in the Canadian High Arctic were the main focus. Dialects and call characteristics were also identified. Budelsky (1992) used triangulation to determine movement, distribution and abundance of bearded seals off Point Barrow, Alaska. This thesis takes Budelsky's (1992) work one step further. First, in analyzing 120 hours of data, as compared to the 5 hours of data analyzed by Budelsky (1992), there is far more information, resulting in a finer resolution of movements. Second, 24 hour sample days provided information on diurnal cycles. Third, the use of satellite images provided information on the distribution of seals in ice habitat.

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CHAPTER 2: INTRODUCTION TO THE BEARDED SEAL

The intent of this thesis was to study the distribution, movement and abundance of bearded seals off Barrow, Alaska, using underwater passive acoustic methods. Very little is known about the behavior of the bearded seal. Natural history information collected on this species has been obtained largely from native hunting. These animals are pagophilic, inhabiting unstable pack ice, and difficult to catch for physical tag and recapture methods. Because the bearded seal is so elusive and unapproachable, acoustic research is an essential, non-invasive tool that can be used for the study of the behavior of these animals. This work builds on the approach of Budelsky (1992), who analyzed approximately five hours of bearded seal recordings. This current project analyzed 120 hours of recordings spread throughout the breeding season. I determined bearded seal location by bioacoustic triangulation. Abundance and distribution were determined from calculated positions, while successive triangulations of individual seals provided data on swim speeds and movements associated with currents and pack ice. Analysis of call rates and number of seals per unit time provided information on diurnal cycles and associations between number of calls per seal.

The acoustic information obtained from this study can aid in determining breeding, territorial and female defense behavior. Female defense behavior may be a function of location (a female on an ice flow), in which case the male would move along with the ice. I propose that, as ice conditions change during the latter part of the season, spacing may disintegrate and seal movement patterns may change. This suggests that breeding strategies alter in accord with the environment. Physical ice conditions as displayed by satellite information were incorporated into the study to compare with acoustic data.

Bearded seal biology:

The bearded seal is the largest of the Arctic phocids (Figure 1), with adult masses ranging from 230 to 390 kg, and length averaging 220 cm, females being slightly longer than males. It has a circumpolar distribution (Figure 2) and is associated with pack ice and leads (Allen, 1880). Adult female bearded seals weigh roughly 250 kg (winter / spring) - 230 kg (summer). Adult males weigh 390 kg (winter / spring) - 244 kg (summer). Pups are born with a dark brown pelage, average 131 cm in length and 32 kg (Burns & Frost, 1979).

The bearded seal derives its genus name, Erignathus, from the Greek word meaning deep jaw. The species name, barbatus, refers to the numerous long moustachial vibrissae. Another interesting feature is the square-shaped front flippers, in which the third digit is slightly longer than the others, giving the flippers a blunt, square appearance (King, 1964).

The bearded seal is a benthic feeder. In general, the diet consists of tanner crab, (Chionocetes spp.), shrimp (Argis lar), clams, snails, sponges, annelid worms and bottom fish such as cod and sculpin. The percentage of particular food items may vary seasonally and geographically (Burns & Frost, 1979).

The trachea of this seal averages 69 rings, of which only the first 6 to 12 are complete. In contrast, all tracheal rings are complete in other Arctic phocids (Burns & Frost, 1979). It has been suggested that the lack of complete rings in the bearded seal may be associated with the variety of vocalizations produced by these animals (Burns & Frost, 1979).

The North Pacific populations of bearded seals occur in the Okhotsk, Bering, Beaufort, Chukchi, and East Siberian Seas, as well as in the Tartar Straight off the coast of Japan. The populations extending from the Bering Sea up into the West Beaufort Sea feed on the continental shelf off the coast of Alaska. In general, these animals winter in the Bering Sea and travel north in the spring following the lead systems that develop as the ice edge begins to recede. A fraction may remain in the Bering Sea, while the majority will travel through the Bering Straight into the Chukchi Sea. A portion of that population will then travel into the western Beaufort Sea. As the ice edge begins to grow in late fall, the animals return to the Bering Sea (Burns & Frost, 1979). The focus of this thesis is the breeding population off the coast of Barrow, Alaska.

Male and female bearded seals in this region reach sexual maturity at 5-6 years of age. Breeding occurs in the spring from mid-April to mid-June (Burns & Frost, 1979). Pupping begins in mid-April and ends in mid-May. Bearded seals are solitary animals, and when found in groups hauled out on ice flows, they are widely spaced (Burns, 1981). Burns (1981) observed that during the breeding season, individual bearded seals, when at the surface, seem to localize in areas roughly 1 to 3 km in diameter for up to four hours. Their breeding system is not known; however, a serial monogamy or a lek system has been suggested (Budelsky, 1992). In serial monogamy, the male defends a female during the period she is lactating to insure exclusive mating privileges after the pup is weaned and when she ovulates (Siniff, Sterling, Bengston & Reichle, 1979 & Siniff, 1981). Burns (1981) suggests that some female bearded seals may mate before the end of lactation. The lek system employs a separate area in which aggregated males defend small territories and perform intricate vocal and visual displays. Females come to this area singly or in groups. Female choice of a mate depends on the performance of the males, which is a function of dominance and rank and overall fitness (Fay, Ray & Kibal'chich, 1981). Lekking behavior is thought to be a tactic used by males when they are not able to monopolize females directly or indirectly. Feeding ecology and available breeding habitat may determine that females need not be clustered, but widely distributed (Gibson and Bradbury, 1986).

The bearded seal is a very important subsistence resource for the Eskimo people. The meat provides food, the fat is eaten or rendered down to oil for fuel, and the pelt is used for clothing, lines, and harnesses, and kayak construction (Boas 1888, Stefansson 1913, Manning 1944 & Krupnik 1978, 1980, 1984). In 1979, the Alaska bearded seal harvest value was $1,801,682 (Burns & Frost, 1979).

Past bioacoustic studies:

Two major studies have focused on the bioacoustics of the bearded seal. Cleator and Stirling (1989, 1990) conducted acoustic studies on bearded seals in the Canadian High Arctic. Budelsky (1992), studied bearded seals off Point Barrow, Alaska. Cleator and Stirling (1989, 1990), attempted to determine late winter distribution using underwater vocalizations and call rates to estimate number of seals in each location they surveyed. They also characterized vocalizations, discussed geographic variations in vocalizations, cycles in call rates, and call propagation in water. The calls were classified as frequency-modulated (FM) calls or those that showed no FM characteristics, such as groans. Categorization of these FM calls produced ascending, descending and mixed slope calls. Further study produced the distinction of solitary calls or calls in sequence. Frequency analysis determined start, end and peak characteristics as well as call duration. These features varied with geographic location suggesting variation in call use and characteristics.

Budelsky (1992) extended acoustic research on the bearded seal by characterizing calls and classifying call types in breeding animals in the Chukchi Sea off the coast of Point Barrow, Alaska. She used triangulation to estimate distribution and movement in consideration of mating systems. Budelsky did not find large scale movements and found that vocalizing seals averaged a nearest neighbor spacing of 2059 m (±1260.9 m).

These studies have shown that bearded seals are highly vocal animals and have a large repertoire of calls, second only to the Weddell seal in Antarctica. The Weddell seal is a polygynous phocid that is commonly associated with fast ice during the breeding season. Both male and female seals of this species vocalize, but the intricate descending trills are thought to be produced only by the males. It has been hypothesized that the males of this species vocalize to attract females and to defend underwater territories (Thomas & Stirling, 1983). Intense vocal activity of bearded seals also occurs during the breeding season and is thought to be associated with breeding activity (Dubrovskii, 1937). Like the Weddell seal, it has been hypothesized that only the adult male bearded seals perform intricate vocalizations (Ray et al., 1969). Further, it is thought that the males hold underwater territories during breeding season and may use the vocalizations to maintain these territories or advertise breeding status to females (Ray et al., 1969). Eskimo hunters report that all "singing" seals they have harvested have been males (Burns & Frost, 1979). Burns (1981) reported repetitive spiral diving by these seals in association with vocalizations, but did not agree that only males vocalize.

The large repertoire of the bearded seal suggests that sound is important in their biology. Shipping traffic and seismic activity has greatly altered ambient levels of noise in the acoustic habitat of this species. Much research has be conducted on the effects of man made noise on behavioral responses of bowhead whales in the Arctic, including Richardson and Malme (1993). Increased anthropogenic disturbance may affect communication, particularly behaviors associated with breeding, by either masking certain frequencies or by dominating the entire spectrum by high source levels. The continued acoustic study of the bearded seal, as well as the environment in which it lives, is essential to further understand this species. Continual technological development and further research may soon allow individual animals to be acoustically tagged. By this, I refer to bioacoustic identification of individuals. Acoustic tagging, along with studies of anthropogenic disturbance, can lead to a better understanding of the management issues associated with this species.

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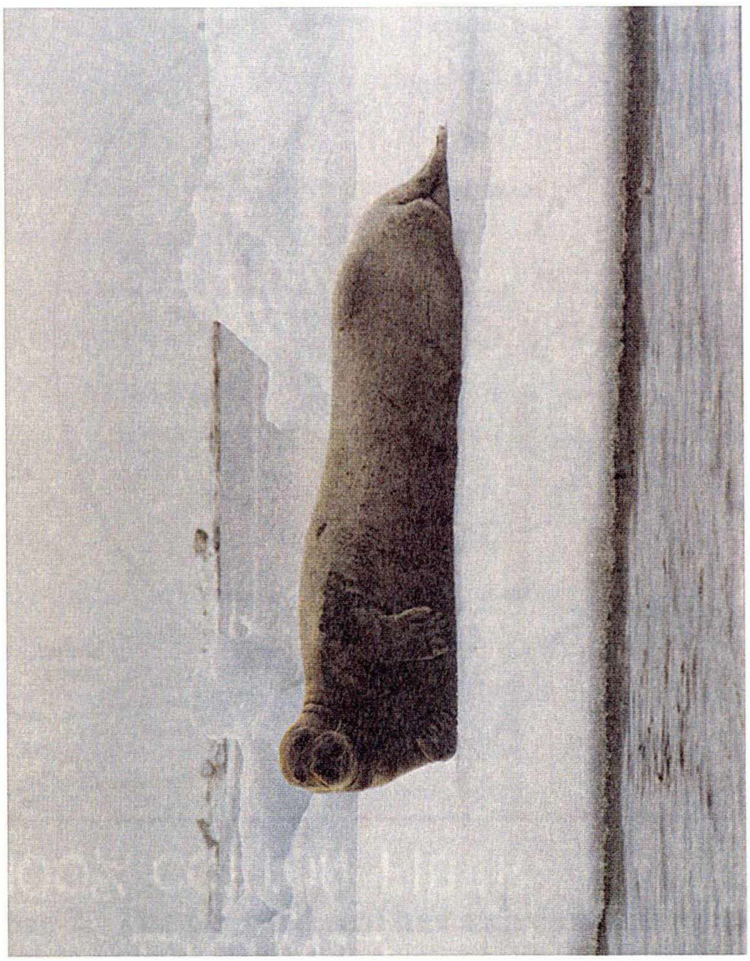

Figure 1. Bearded seal.

Figure 2. The bearded seal has a circumpolar distribution.

CHAPTER 3: METHODS

Location of study:

I collected bearded seal vocalizations recorded incidentally as part of the 1993 Bowhead Whale Census conducted by the North Slope Borough Department of Wildlife Management (George et al., 1995). Recordings took place during the spring migration of the bowhead whales off the coast of Point Barrow, Alaska (Figures 3 and 4). The census consisted of 46 days from 15 April to 30 May 1993, utilizing various sets of hydrophone arrays. Placement of each hydrophone array was along the edge of the land-fast ice. The total number of hydrophones varied from three to five, and the linear pattern of each array varied according to the position and angle of each unit relative to one another and a Global Positioning System (GPS) location. The depths of the hydrophones ranged between 6 to 15 meters. Each hydrophone was attached to a sonobuoy which transmitted the signal to multichannel recorders and then to multichannel 2 hour digital analog tapes (DAT's). The array configurations changed due to changing ice conditions, as well as in the attempt to obtain the best pattern for locating migrating whales along the coast of Alaska (George et al., 1995). A permanent hydrophone position at Carolyn perch (71° 20′ N & 156° 48′ W) was used in the majority of the arrays.

Tape selection:

I set criteria for tape selection before tapes were analyzed. I chose to analyze five 24 hour periods, spaced about a week apart throughout the season, to examine if there were any changes in the local movement and distribution of the seals. Tapes selected were as clear as possible from whale song, documented mechanical problems, high ambient noise and / or motor boat activity problems. All arrays included the Carolyn perch. The five days and their respective hydrophone arrays are described in Table 1.

Data analysis:

Analysis of bearded seal vocalizations consisted of playing back each tape on a multichannel recorder that was connected to a Macintosh computer. I used the Canary 021701 program, developed at the bioacoustics laboratory in the Cornell Lab of Ornithology under the direction of Dr. Chris Clark, to analyze the acoustic data (Clark et al, 1986). The sampling rate of the program was set to 2 Khz, which limited the sonagraph window frequency bandwidths. Because this program was developed for the purpose of bowhead whale research, the frequency bandwidth was much lower and narrower than needed to fully view the entire range of bearded seal vocalizations, despite the fact that the entire bandwidth, 0 - 6 KHz, was available on the DAT's. The bandwidth available in the Canary browser window varied with the number of hydrophones. In a four hydrophone array, it ranged from 0 Hz - 630 Hz; while in a five hydrophone array, it ranged from 0 Hz - 500 Hz. In both cases, the bandwidth was sufficient to locate seals. I documented and categorized call types as close as possible to past research classifications (Cleator and Stirling, 1989 & Budelsky, 1992). However, I gave some calls arbitrary names when a match could not be made. I was consistent as possible in classifying calls. I coded ambient noise for each tape, as either high, medium or low, based on the sound levels recorded along with the vocalizations. Activity level, as determined from the rate of vocalizations on the particular tape, was also documented as high, medium or low.

The Canary program calculated seal locations as described by Clark et al. (1986). Basically, computer programs triangulated a location based on the time differential of the signal arriving at each of the hydrophones, as seen in Figure 5. Correlations of received signals aided when considering a location for acceptance. Correlation, or coherence, is the similarity of a received signal at two spatially separated receivers. Coherence is affected by the separation and orientation of the two receivers, the bandwidth used, the integration time employed, and the multipath nature of the medium. When there are many multipaths, coherence is low (Urick, 1983). Figure 6 is an example which shows the location of a source from the three hydrophones fastened to the landfast ice. Correlations converge and form a triangle in which the source of the signal is most likely to be. The higher the correlation, the smaller the area. The length of the triangle is the range error and the width is the bearing error. The smaller the error values, the higher the probability of getting an accurate location. I documented correlations, calculated by the computer, for sample days 2 - 5 for each location. I then took the correlations for each location and qualitatively classified them as: Not Good, Medium, Fair, Good, and Great, based on my evaluation of the original correlations. It was possible to reject a number of correlations to obtain better range and bearing errors. This was done in a consistent manner. Also a record of the correlation ratio [rejected: total after computer calculation] was kept. Day #1 employed a three hydrophone array which is the minimum amount for triangulation of an animal. This resulted in only three correlations being available, and therefore no correlations were rejected.

I determined criteria for accepting a calculated location based on bearing and range errors. Using criteria accepted by Budelsky (1992), a bearing error of 1° or less was established. I used the Budelsky (1992) nearest neighbor minimum value of roughly 1 km and Burns' (1981) observation on individual localization of 1 - 3 km diameter to establish a range error of 1 km or less. Basically, if the location had a range error or a bearing error larger than 1 km or 1°, the location was not accepted. I did this to be able to have more accurate locations. Once a location was accepted, it was plotted onto a map. Each map was tested for locations that fell within 30° zones along the array. These 30° zones are considered to be grey areas in which range errors increase, resulting in unreliable locations. I decided to use the locations that fell with in the 30° zones for qualitative inspection of the data.

Analysis of the location data began with separating and grouping the individual locations into individual seals. The criteria used to accomplish this began with the assumption of a 1 km radius for each seal from the last documented location. Again, this was based on Budelsky (1992) and Burns (1981). Basically, I assumed that there would only be one seal located within a 1 km radius of a calculated acoustic location. It was also assumed that all those seals were male, based on the hypothesis that males vocalize to maintain territories or advertise breeding status to females. Any overlapping calls were considered to be separate seals, regardless of the 1 km radius rule. Any call that was more than 1 km distant from another was considered a separate individual, unless time between locations allowed for the possibility that the same seal could swim the calculated distance, or known multipath problems were occurring, or array error gains allowed for the possibility of location error.

Multipath refers to an acoustic signal that uses several different paths to travel through the medium, because it passes through different water masses and reflects off obstacles such as sea ice. The signal arrives at the receiver via separate paths at slightly different times, resulting in a shadow or echo. When calculated, these echoes produce false locations. Unfortunately, the 1993 recordings were plagued by multipath difficulties that arose from array configuration and ice conditions. Multipath randomly affects location calculations. In the case of multipath problems, I used correlations, correlation ratios, and array error gains to determine individual seals. If correlations were classified as Medium, Not Good and Fair, and the number of correlations rejected was higher, I attributed locations being off their true position to multipath.

I obtained an array error gain plot for each array to determine the sensitivity range of the arrays used in recording. Each plot designated the areas in which the range error value for calculating locations increased, and by what amount, due to the configurations of the array. I also used swim speed and call sequencing to determine movement. I observed during the analysis that certain types of calls fell into a temporal sequence. The sequencing may have been one animal vocalizing three different calls or three animals repeatedly vocalizing the same call. Because of the 1 km radius assumption, I viewed it as one animal. The sequencing aided in following and defining individual seal movement. After I grouped individual seal locations, I tracked movement using an X-Y plot graphing tool on Microsoft Excel. I then analyzed distribution and movement changes in association with ice conditions, as recorded in daily logs during the census and by remote sensing data obtained for the Barrow area.

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Table 1: Sample days and their respective arrays.

Sample Day	Date	Array	# of Hydrophones
1	16 April 1993	A	3
2	23 April - 24 April 1993	D,E	5,4
3	5 May 1993	J	4
4	15 May - 16 May 1993	N	5
5	28 May 1993	U	4

Arrays are given letter designations.

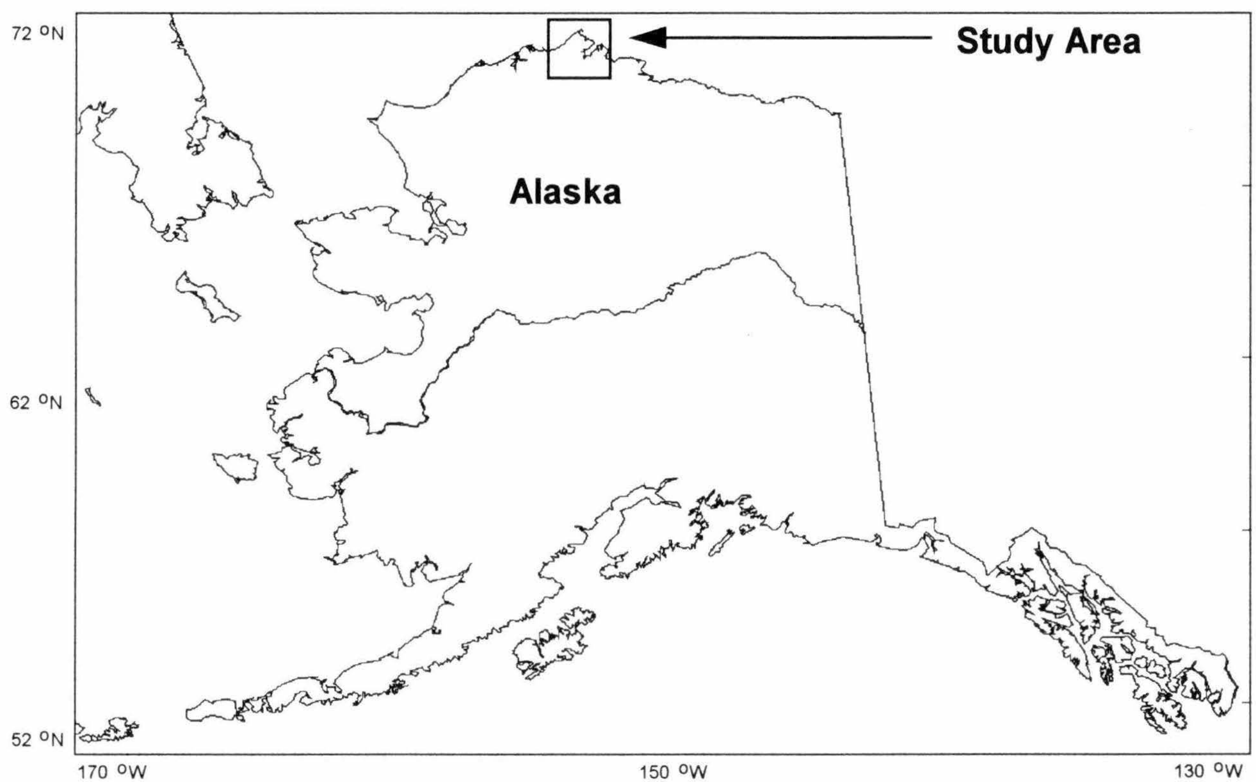

Figure 3. Map depicting Alaska.

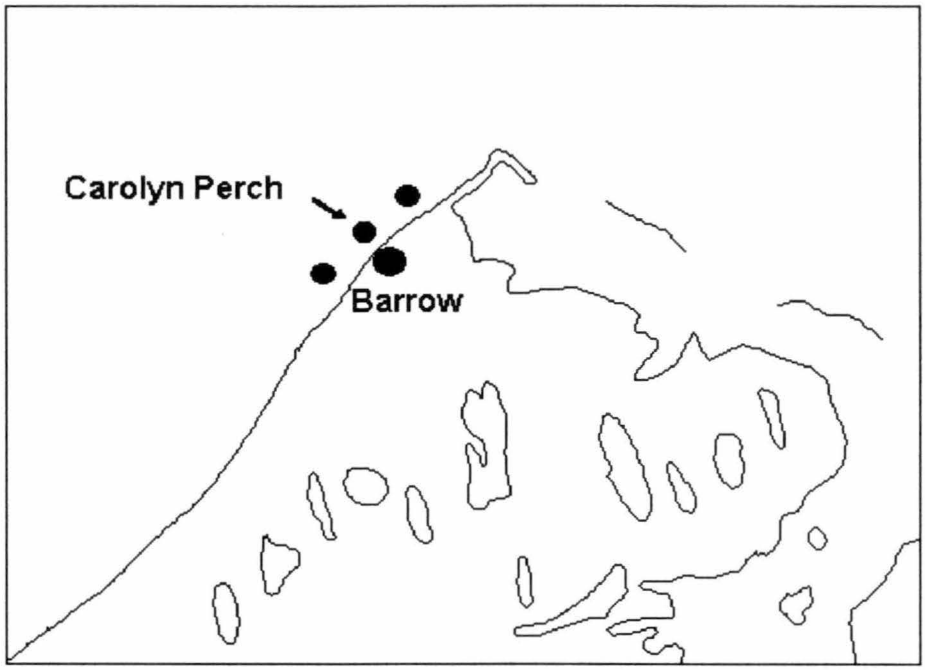

Figure 4. Map depicting the location of Barrow, Alaska. The illustration of Carolyn Perch and the hydrophone array is not to scale. Hydrophones were usually spaced about 1 km apart along the lead edge.

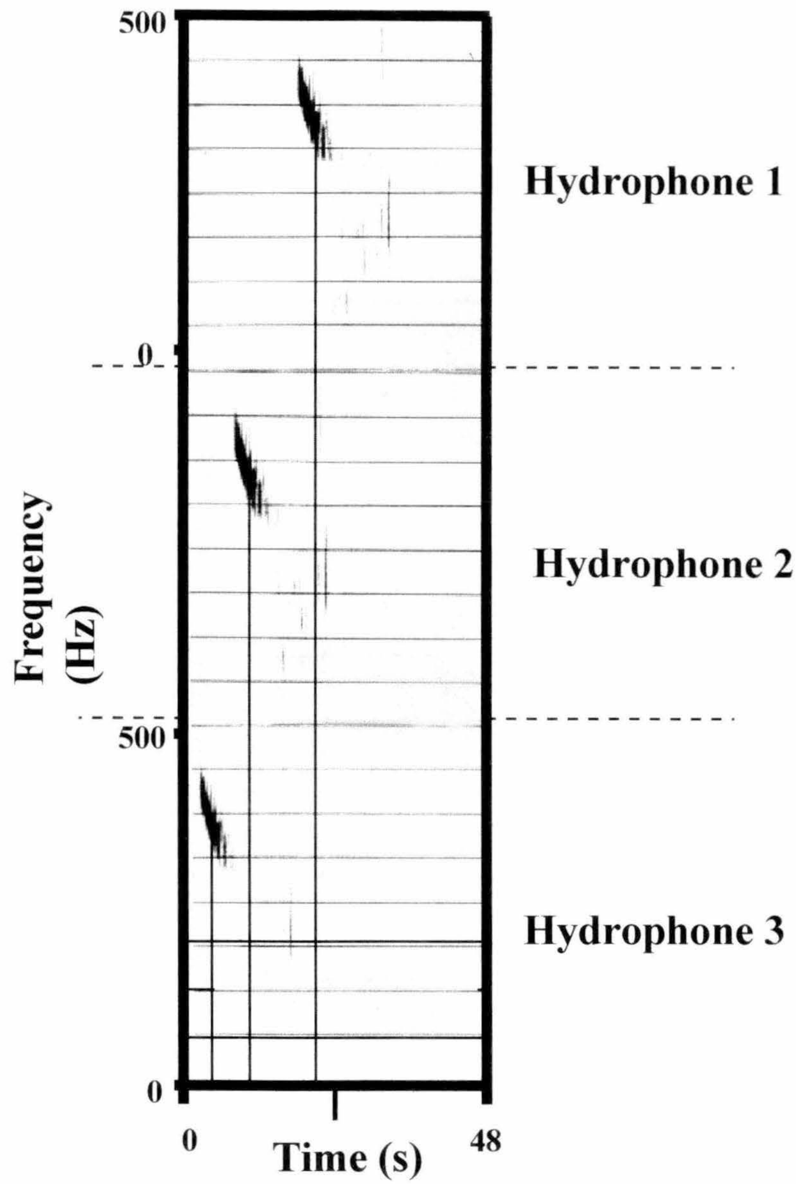

Figure 5. This is an example of how triangulation takes place. The bearded seal call will be received at the three hydrophones at different times. By calculating the time difference, you can triangulate the position of the source.

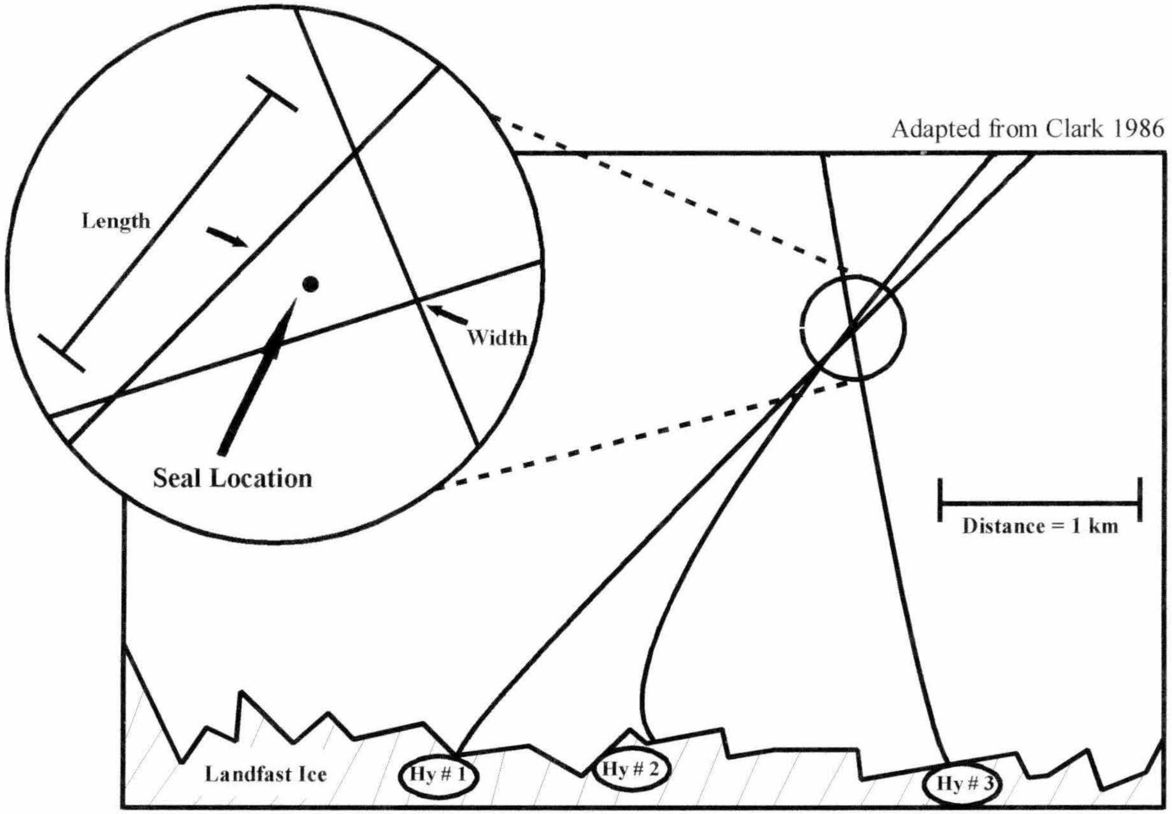

Figure 6. Diagram depicting an acoustic location calculated from the intersection of the three correlations. The seal is located at the center of the triangle. The length and width of the triangle depict the range error and bearing error, respectively, of the seal acoustic location.

CHAPTER 4: VELOCITY AND BEARING

Introduction:

The majority of the life of a seal is spent at sea foraging, mating, seeking protection, and socializing. Behavioral requirements and energetic costs determine the swim speeds of a seal at sea. Foraging may require slower speeds for longer periods of time, while territorial or female defense may require faster speeds for shorter periods of time. Therefore, in general, research on swim velocity can shed light on foraging, diving and mating behaviors, metabolic rates, energetics, physical form and shape, and drag.

Swim velocity patterns in marine mammals have been studied previously in the laboratory and at sea. Le Boeuf et al. (1992) used northern elephant seal (Mirounga angustirostris) swim speeds to categorize dive types. They then hypothesized dive function and relevance to a Kooyman et al. (1980) study of oxygen utilization and aerobic dive limits in seals. Ponganis et al. (1992) used swim speeds to model metabolic rates of freely diving northern fur seals (Callorhinus ursinus). Ponganis et. al. (1990) looked at swim speeds in various otariid species to calculate transit distances to feeding areas and to determine if the animals travel at estimated Minimum Cost of Transport (MCT) velocities. They also calculated metabolic rates and estimated energetic costs of various activities during a foraging trip. Ponganis et. al. in 1993 recorded swim speeds in Weddell seals (Leptonychotes weddellii), along with muscle temperature during diving.

Swim velocities gathered from previous studies show that, in general, most pinnipeds travel at similar speeds (Table 2). Included in this table are bearded seal swim velocities as observed by Naito (1979) and those acoustically located and calculated by Budelsky (1992).

The purpose of this study was to calculate swim velocities from acoustically located bearded seals and compare the results to past studies to see if swim speeds determined in this fashion are comparable to estimates based on other techniques. I also studied seal bearings in association with sea currents for swimming behavior and the relevance to MCT.

Methods:

Methods for tape selection, calculated seal locations, and grouped seal locations are described in Chapter 2. Once clumped, I statistically analyzed swim velocities and grouped them into swim velocity categories consisting of: 0-0.1, 0.1-0.5, 0.5-1, 1-2, 2-5, 5-10, and 10-100 m/s. The percentage of swim velocities falling between 0-1 m/s, 1-1.5 m/s, 1.5-2 m/s, 2-5 m/s, and 5-100 m/s were calculated. I assumed values greater then 5 m/s to be analytical errors based on multipath distortions of swim speed.

I calculated seal swim directions, hereafter to be referred to as seal bearings, from X-Y coordinates of located seals. I correlated seal bearings with data on surface water currents for each sample day to evaluate the possible effects of seal bearings into or along with the currents on swim velocities and MCT. I calculated the percent of seal bearings into or along with the current for each sample day and then grouped their associated velocities into the above swim velocity categories. I then compared these velocities to the overall swim velocities for each day. Bearings of seals from Carolyn perch are values associated with the position of the seal from Carolyn perch, and are different values than the previously mentioned seal bearing values. Bearings of seals were collected with the original triangulation data.

Results:

I analyzed 120 hours of acoustic data, resulting in a total of 5850 locations. Analysis and clumping of the locations produced 1240 seals; 636 seals were located only once and 604 seals were tracked to one or more points after the original location. Traveling seal tracks ranged from 1 - 291 points, excluding the initial location.

Figure 7a and Table 3 show the percentage of overall swim speeds that fell in the velocity groupings. The data indicate that greater than 55% of swim velocities for each day fall between 0 - 1 m/s, and about 10% lie between 1 - 1.5 m/s. Roughly 10% lie between 5 - 100 m/s and are thought to be due to the multipath problems and array error gains discussed in the methods section. Appendix 1 shows the 1993 surface current data for each of the sample days. Figures 7b,c show seal swim speeds associated with currents. Figures 8a-l show 1993 seal bearings from Carolyn perch vs time for 12 tracks. Figures 9a-e show seal bearing in relation to surface currents, with the arrows indicating the bearings of the currents. I grouped seal bearings falling between each degree to obtain a frequency of seal bearings. Currents on days 1-4 generally flowed southwest, while currents on day five flowed northeast. Seal bearing frequency was larger across the currents in days 1-3 & 5, and a larger proportion of seals swam along with the currents than into the currents. Day 4 did not exhibit any form of bearing preference. Figure 10 indicates the percent of seals swimming into and along with the currents. Table 4 also suggests that the majority of seals swam in directions other than directly into or along with the current. Tables 5 & 6 show the swim velocity frequencies of seals swimming into and along with the current. The majority of swim velocities associated with the current remained within previously documented swim speeds. The seals swimming into the current showed a higher percentage of swim velocities in the first velocity range category of 0 - 0.1 m/s. Those that swam along with the current showed a higher percentage of swim velocities in the second velocity range of 0.1 - 0.5 m/s.

Discussion:

Close to 90% of the velocities fall with in previously documented velocities for other pinnipeds, including bearded seals. The majority, 55 - 72%, fall between 0 - 1 m/s and are within observed mean velocities. I arbitrarily called them wandering velocities. Only 9 - 16% fall between 2 - 5 m/s. The value 2.78 m/s is thought to be maximum cruising speed of the Weddell seal (Kooyman 1981). The behavior associated with wandering speed may be foraging or travel, while behavior associated with maximum cruising may be defense of territory or females.

The bearded seal is a benthic feeder, foraging on sessile or slow moving organisms. Therefore, slower swim speeds are sufficient to capture food. Also, males that display in a lek system usually vocalize while swimming slowly, as documented for walrus (Ray & Watkins, 1975). Slower speeds have also been observed in the bearded seal spiral dives (Burns, 1981). Territories are usually maintained with vocalizations and posturing. However, defense may at times require swift swimming or action against the invader. This has been observed in various terrestrial territory holders including the Steller sea lion, and in harem defenders like the elephant seal. Male Weddell seals are thought to hold underwater territories and may swim quickly to attack an invader in defense of the breathing hole or area (Thomas & Stirling, 1983). The swim speeds in this study may reflect the various types of behaviors that occur during the breeding season of bearded seals. The animals may spend most of their time foraging or displaying, as exhibited by the 55 - 72% wandering speeds, and a lesser amount of time swimming to defend territories or females, as reflected by the 9 - 16% values of maximum cruising speed.

The majority of velocities bearing into or along with the currents remained within previously documented swim speeds. Currents may have caused a shift in swim velocities of seals swimming into or along with the currents. Slower speeds may reflect the seals having to fight against the current, or speeds may have been reduced to conserve energy. Faster speeds, while swimming along with the current, may have been the result of the compounded effects of currents on slower active swimming by the seals. Overall, however, most seals swam across the currents.

Bearings from Carolyn perch vs time information, as seen in Figures 8a-l, suggests that the seals tracked over long periods either traveled in a relatively constant overall direction or maintained position. Behaviors associated with bearings from Carolyn perch suggest foraging, search for females or territory defense. Adult bearded seals forage during the breeding season as documented in many studies including Burns and Frost (1979). When searching for food, the animal may swim over a large area. Also, because females are very widely spaced, males may have to swim in search of them. If bearded seals defend a territory, they may maintain their positions. These seals do not migrate during this time of year, and most are in breeding condition (Burns, 1981). Females bear young on ice floes and then nurse their young for roughly 18 days before weaning (Burns, 1981). A male may defend a female on an ice floe while in the water displaying vocally. Foraging may also take place during this activity. Bearings and swim velocities indicate that these animals may maintain their locations and save energy by swimming across the currents and using MCT.

This study supports the hypothesis that acoustic calculation of bearded seal swim velocities can yield results that correspond to other methods and may be the preferred method for use on vocal animals that are difficult to handle or radio track in the field. I was unable to use 10% of the swim speeds because of multipath problems. Improvements can be made to limit multipath problems, including research on correction values for multipath and design of optimal hydrophone arrays that limit errors. In summary, swim velocity data found in this study support existing data for other pinnipeds and suggest that bioacoustics can be a useful and powerful tool for studying movements of free ranging seals.

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Table 2: Velocities of various pinnipeds.

Species	Mean Swim Velocity (m/s)	Max Swim Velocity (m/s)	References
Northern elephant seal	1.5 Descent	5.4***	Le Boeuf et. al., 1992
	1.2 Ascent		Bartholomew, 1952
	Bottom of dives		
Southern elephant seal		6.7*	Laws,1956
Northern fur seals (2)	1.6 Deep dives	3.3 Diving '	Ponganis et. al., 1992
	1.4 Shallow dives		Ponganis et. al., 1990
Weddell seal	1.3	2.78	Ponganis et. al. 1993
			Kooyman, 1981
Harbor seal	1.4**		Davis et. al. 1985
Grey seal	1.3**		Thompson et. al. 1993
Galapagos sea lion	2.0 Diving	5.3 Diving	Ponganis et. al., 1990
	1.4 Surface	2.8 Surface	
Hooker's sea lion	1.4 Diving	4.8 Diving	Ponganis et. al., 1990
	1.2 Surface	3.9 Surface	
Galapagos fur seal	1.5 Diving	3.1 Diving	Ponganis et. al., 1990
Ringed seal	1.33	6.0	Kelly, Personal Comm.
Bearded seal	0.422		Naito, 1979
	0.14		Budelsky, 1992

' - Estimated swim speeds from velocity meters and Swim Speed Distance Meters (SSDM).

* - Estimated swim speeds based on TDR information.

** - Velocities calculated from flume studies.

***- Estimated swim speeds based on field observations.

Table 3: 1993 Bearded seal percent swim velocity

Range (m/s)	**Day 1 %**	**Day 2 %**	**Day 3 %**	**Day 4 %**	**Day 5 %**
0.0 - 0.1	12.6	6.8	5.5	11.6	4.9
0.1 - 0.5	32.1	31.1	30.5	44.4	24.9
0.5 - 1.0	18	19.3	29.9	16.0	26.1
1.0 - 1.5	9.6	11.3	10.2	9.3	12.6
1.5 - 2.0	5.0	7.1	4.9	3.8	7.3
2.0 - 5.0	13.3	15.5	10.7	9.3	12.2
5.0 - 10	5.0	5.3	4.7	4.0	7.1
10 - 100	4.4	3.6	3.6	1.6	4.9
Total	100	100	100	100	100
% Sum of 0.1 - 1	62.7	57.2	65.9	72.0	55.9
% Sum of 10 - 100	9.4	8.9	8.3	5.6	12.0
Average Swim Speed	0.92	1.05	0.91	0.75	1.05
Variance	1.06	1.12	0.85	0.85	0.95

Table 4. Percent seal bearing

Day	Bearing into Current %	Bearing with Current %	Bearing out of Current %
1	2.9	5.4	91.7
2	5.7	15.1	79.2
3	3.0	13.0	84.0
4	4.1	5.6	90.3
5	2.4	15.6	82.0

Table 5. Swim velocities of seals bearing into the current

Range (m/s)	Day1 %	Day2 %	Day3 %	Day4 %	Day5 %
0.0 - 0.1	24.1	11.6	14.3	20.8	35.0
0.1 - 0.5	38.0	44.2	57.2	58.3	35.0
0.5 - 1.0	13.8	25	9.5	14.6	5.0
1.0 - 1.5	6.9	1.9	0	2.1	10.0
1.5 - 2.0	6.9	5.8	0	0	5.0
2.0 - 5.0	6.9	7.7	9.5	2.1	0
5.0 - 10	0	1.9	9.5	0	5.0
10 - 100	3.4	1.9	0	2.1	5.0
Total	100	100	100	100	100
% Sum of 0.1 - 1	75.9	80.8	81.0	93.7	75.0
% Sum of 10 - 100	3.4	3.8	9.5	2.1	10.0
Average Swim Speed	0.62	0.77	0.52	0.35	0.38
Variance	0.67	1.23	0.47	0.19	0.22

Table 6. Swim velocities of seals bearing along with the current

Range (m/s)	Day1 %	Day2 %	Day3 %	Day4 %	Day5 %
0.0 - 0.1	26.0	5.9	5.6	20.0	6.1
0.1 - 0.5	48.1	50.4	54.0	66.2	37.9
0.5 - 1.0	16.7	20.4	34.8	9.3	43.9
1.0 - 1.5	5.6	11.0	4.5	1.5	8.3
1.5 - 2.0	1.8	2.2	0	0	2.3
2.0 - 5.0	1.8	7.3	1.1	1.5	1.5
5.0 - 10	0	1.4	0	0	0
10 - 100	0	1.4	0	1.5	0
Total	100	100	100	100	100
% Sum of 0.1 - 1	90.8	76.7	94.4	95.5	87.9
% Sum of 10 - 100	0.0	2.8	0.0	1.5	0.0
Average Swim Speed	0.40	0.66	0.49	0.34	0.63
Variance	0.37	0.48	0.18	0.34	0.18

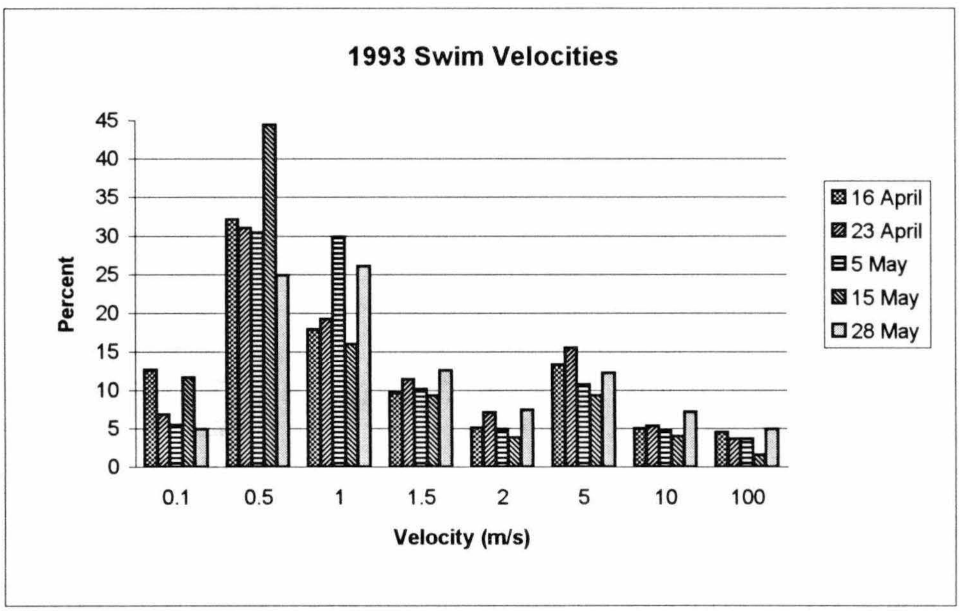
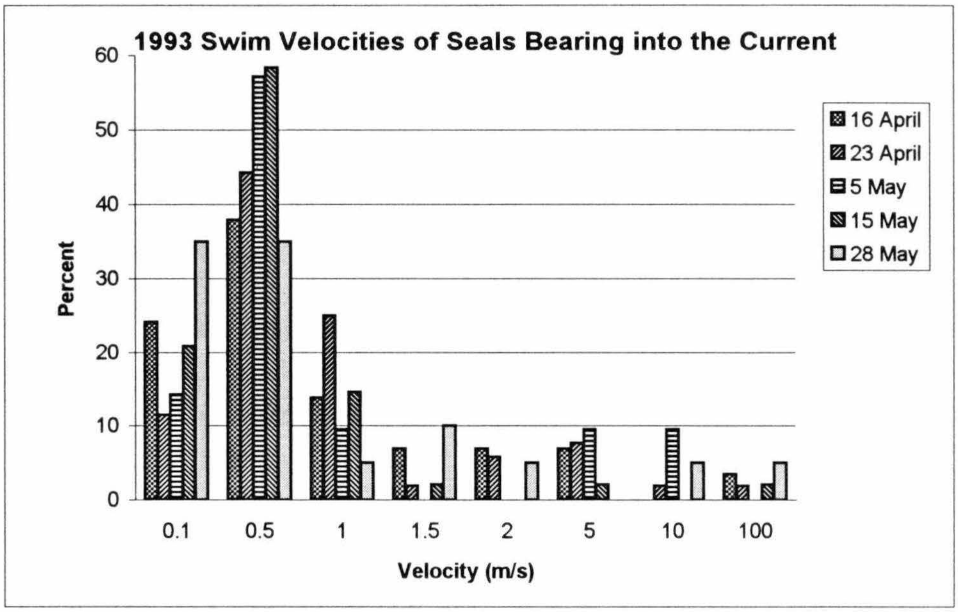


Figure 7a. 1993 Overall swim velocities for various velocity categories. Velocities greater than 5 m/s were atributed to errors associated with multipath.



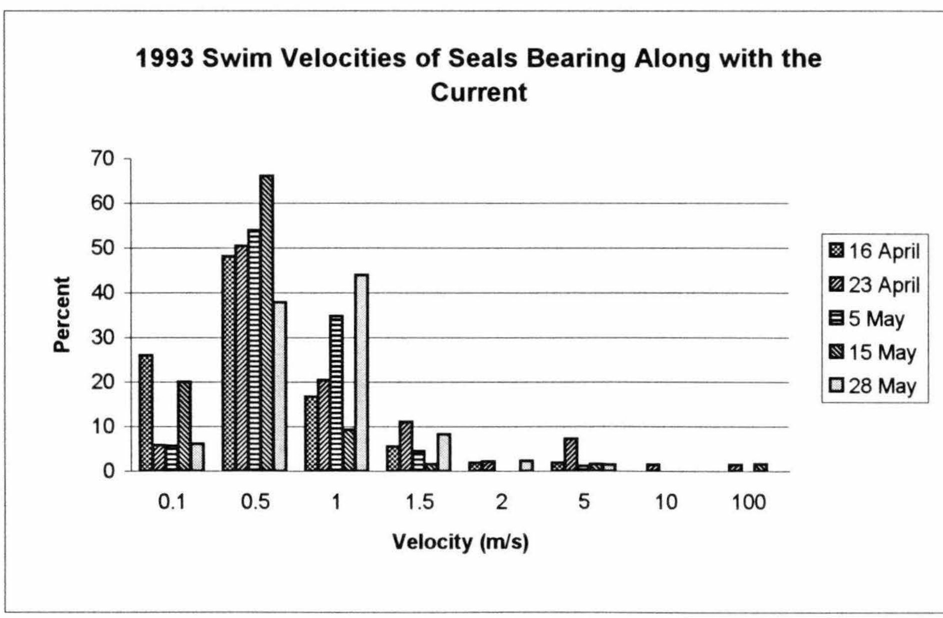
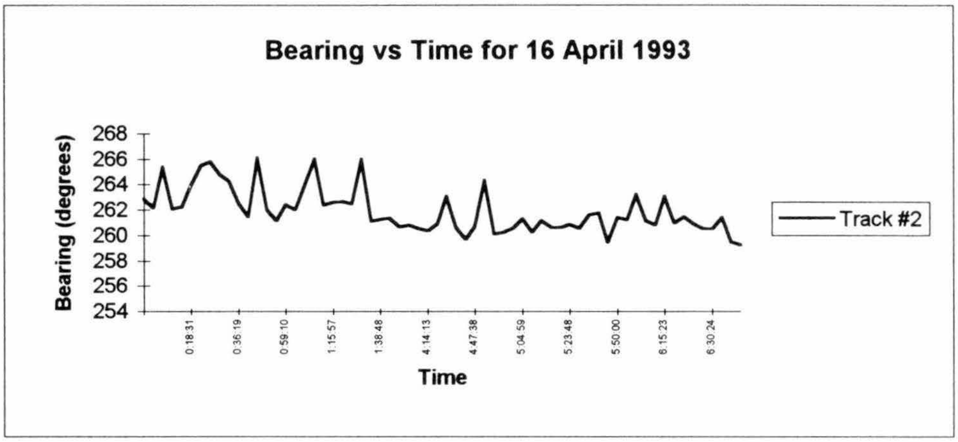
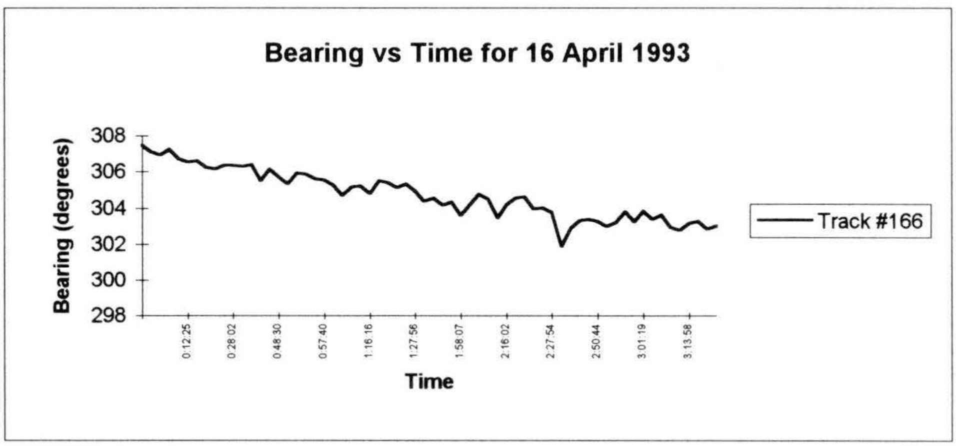


Figure 7 (b and c). 1993 Swim velocities for seals swimming against and with the currents. Note that overall, velocities are faster for seals swimming along with the currents, and slower for seals swimming against the currents.





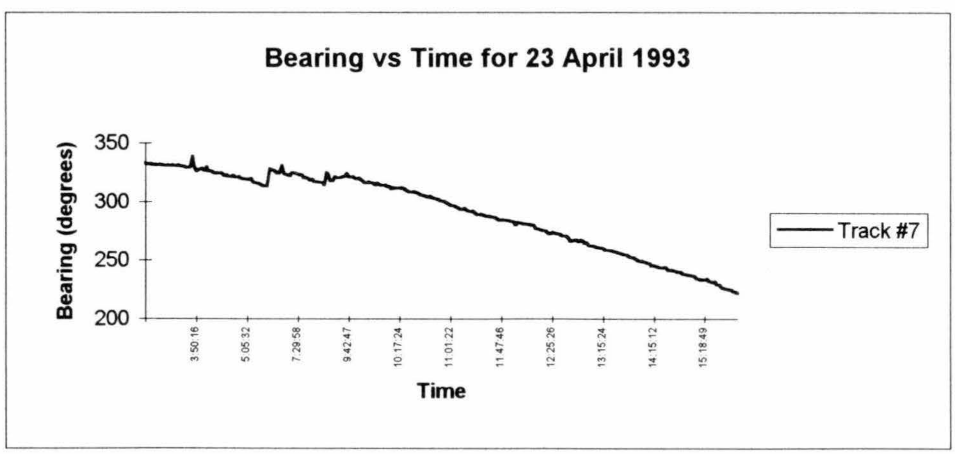


Figure 8(a-c). Examples of tracking seals over time. Bearings are from Carolyn Perch. Distances from Carolyn Perch are not shown here.

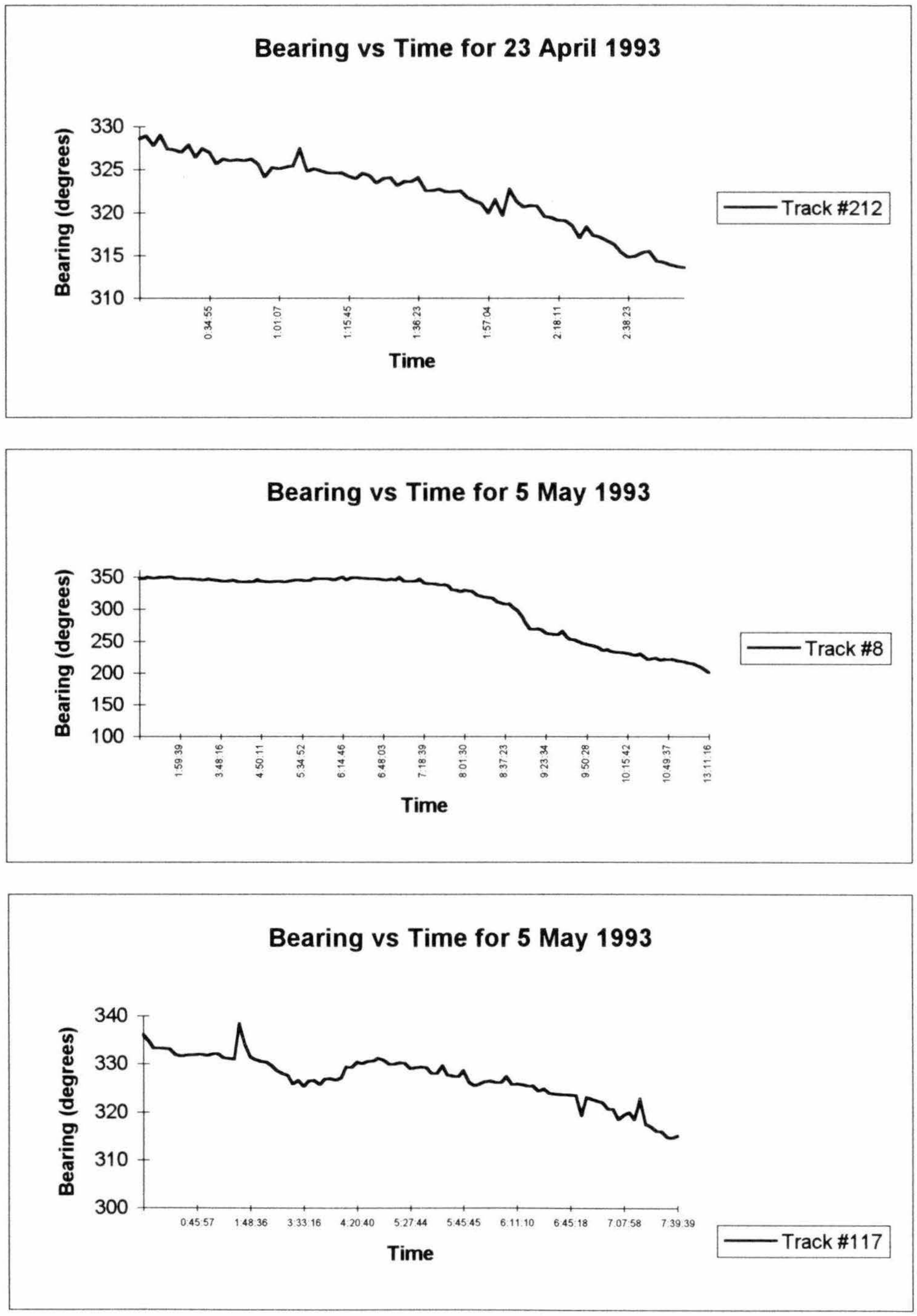
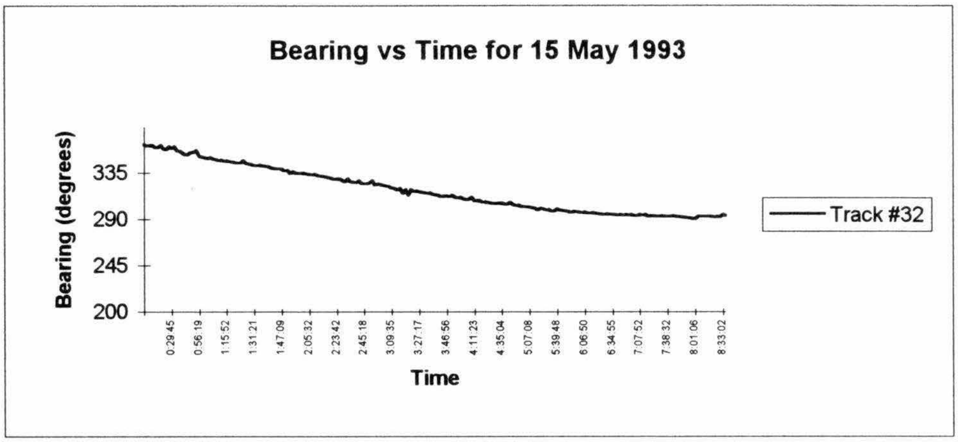
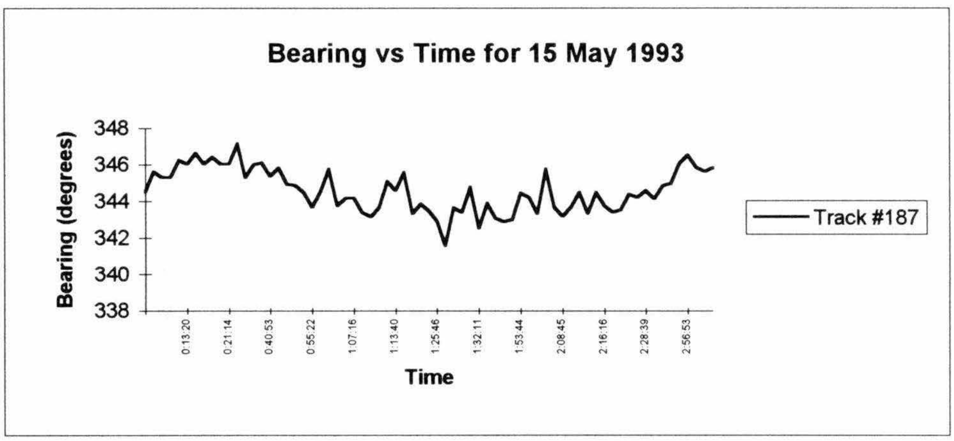


Figure 8(d-f). Examples of tracking seals over time. Bearings are from Carolyn Perch. Distances from Carolyn Perch are not shown here.





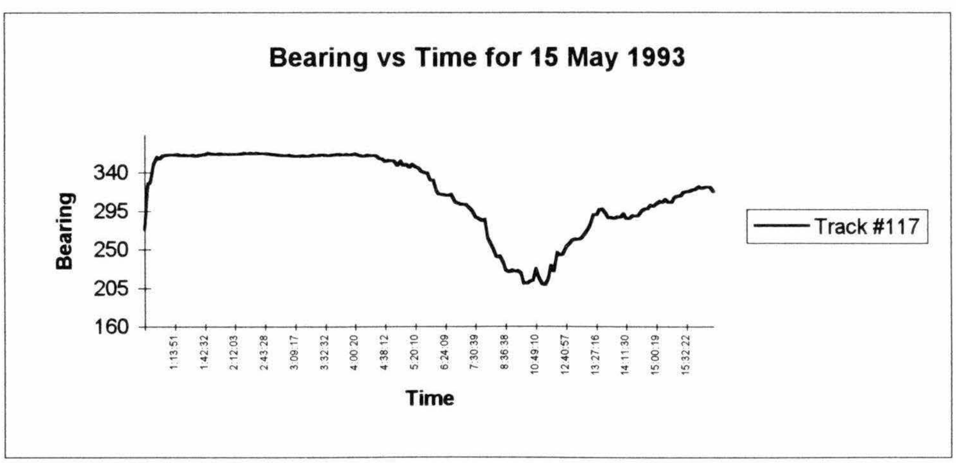


Figure 8(g-i). Examples of tracking seals over time. Bearings are from Carolyn Perch. Distances from Carolyn Perch are not shown here.

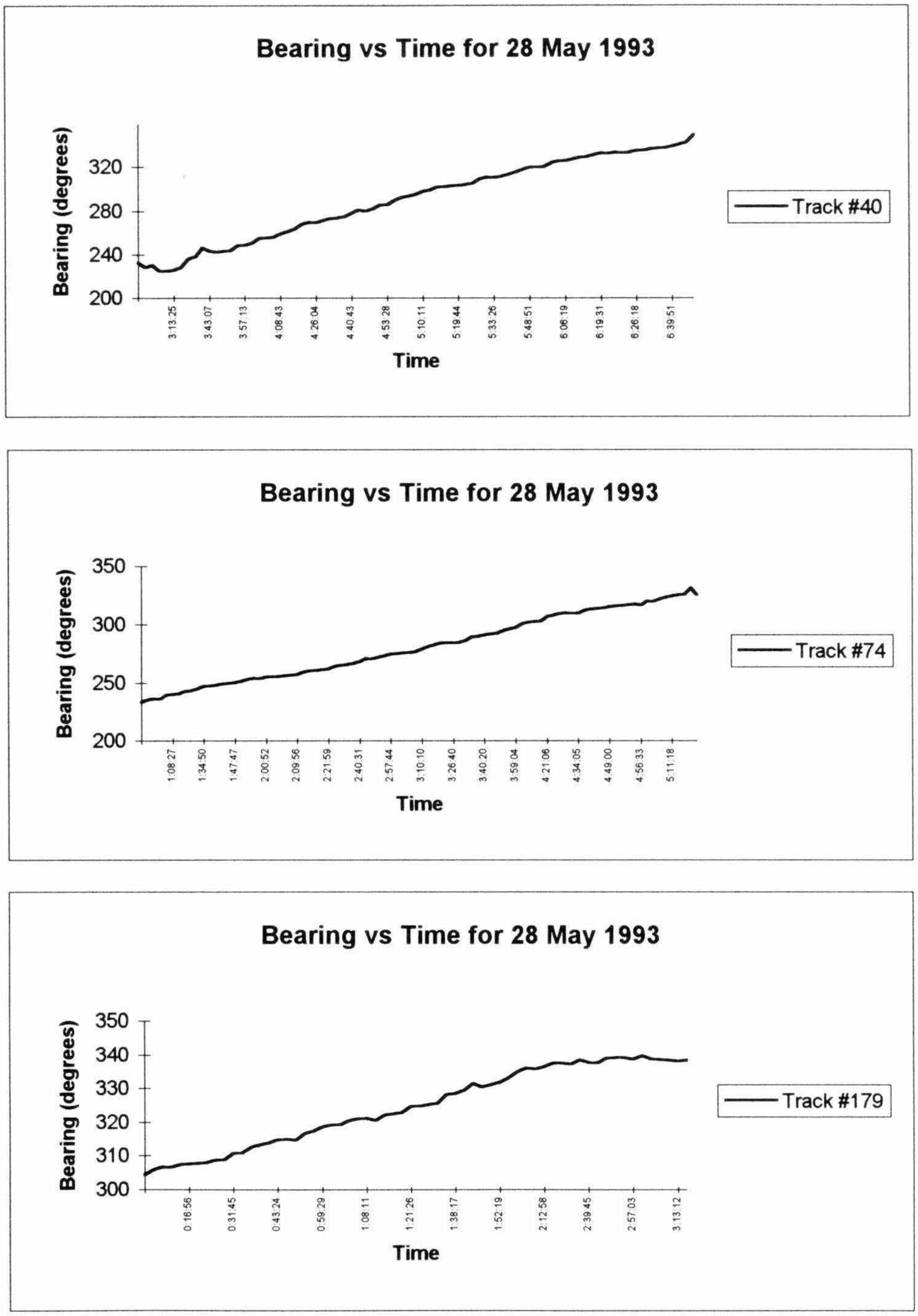


Figure 8(j-l). Examples of tracking seals over time. Bearings are from Carolyn Perch. Distances from Carolyn Perch are not shown here.

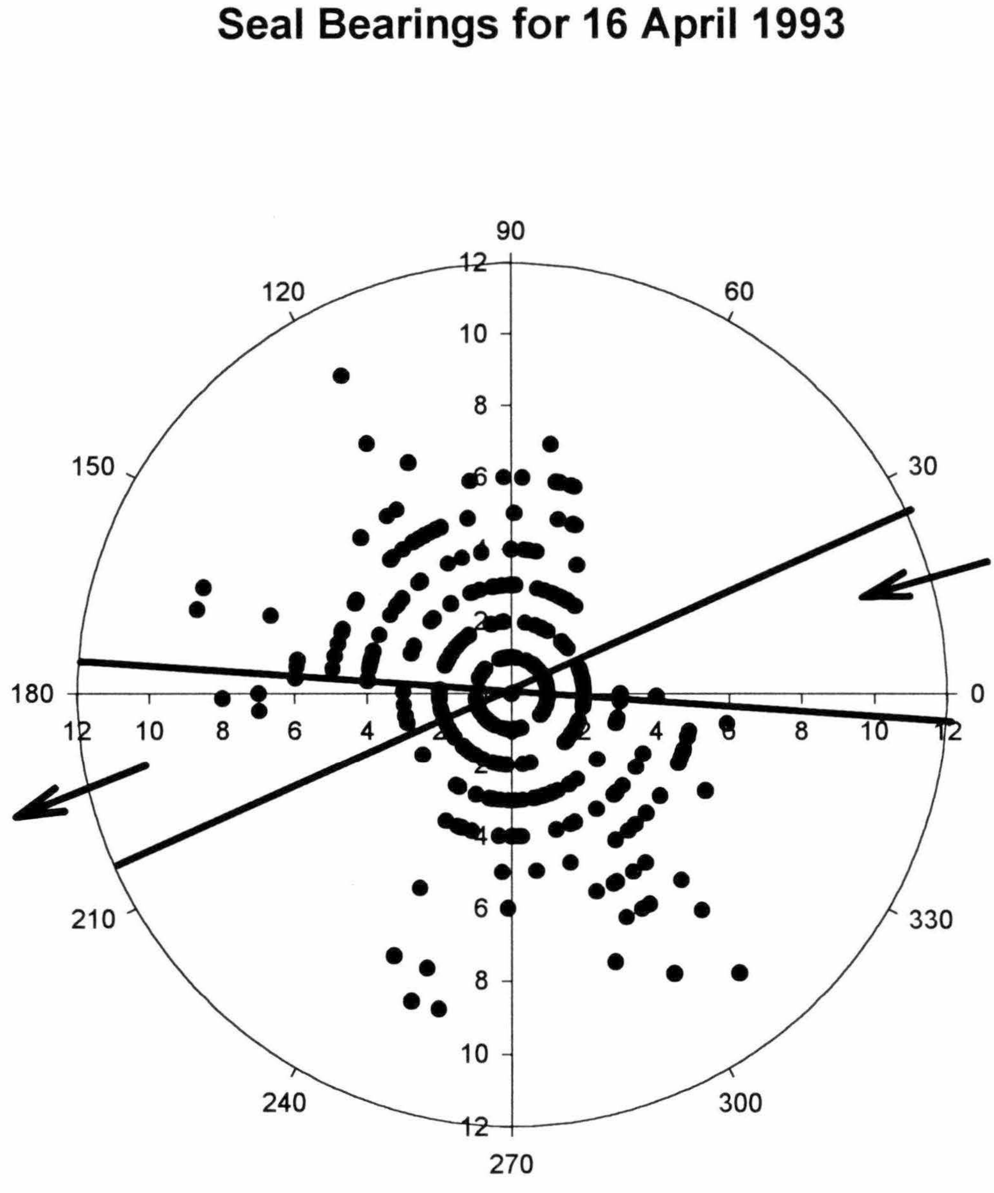


Figure 9a. Polar plot depicting the bearings of seals for the 16th of April. The lines show the bearing range of the currents for that day and their direction of travel.

Seal Bearing for 23 April 1993

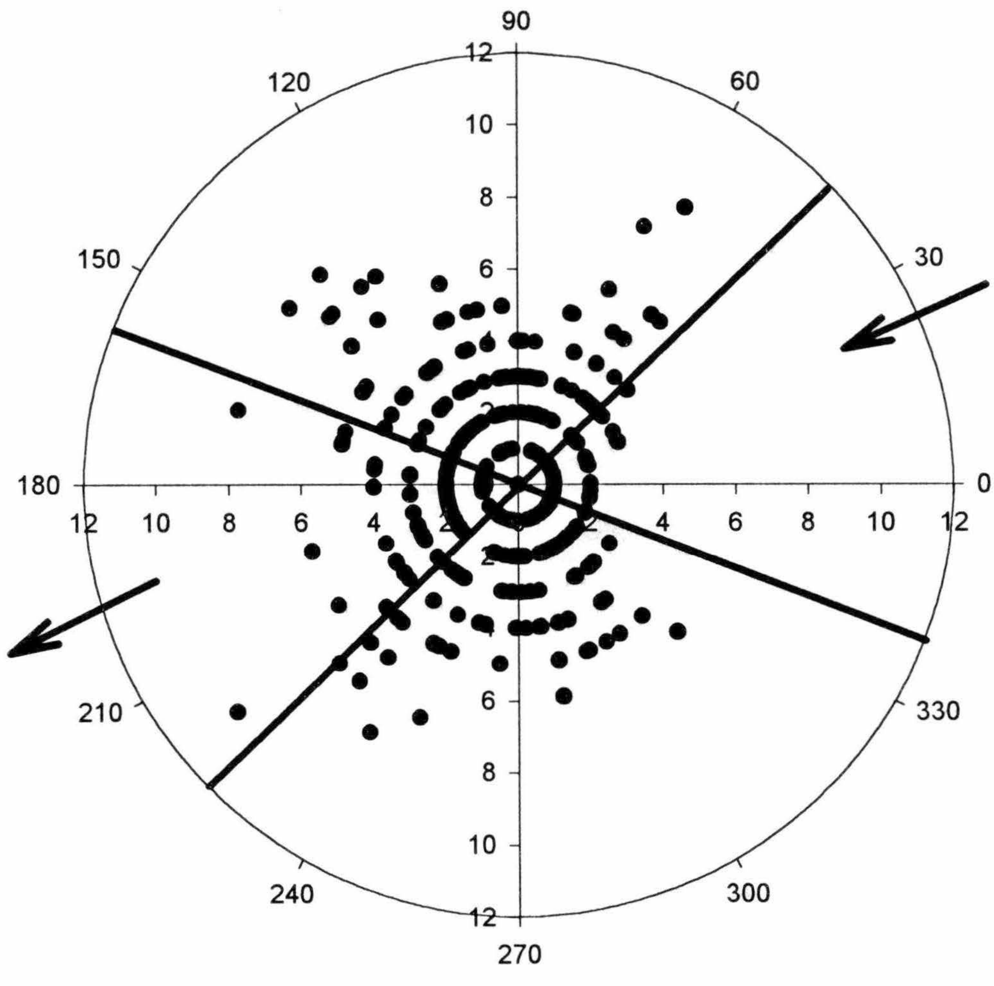


Figure 9b. Polar plot depicting the bearings of seals for the 23th of April. The lines show the bearing range of the currents for that day and their direction of travel.

Seal Bearing for 5 May 1993

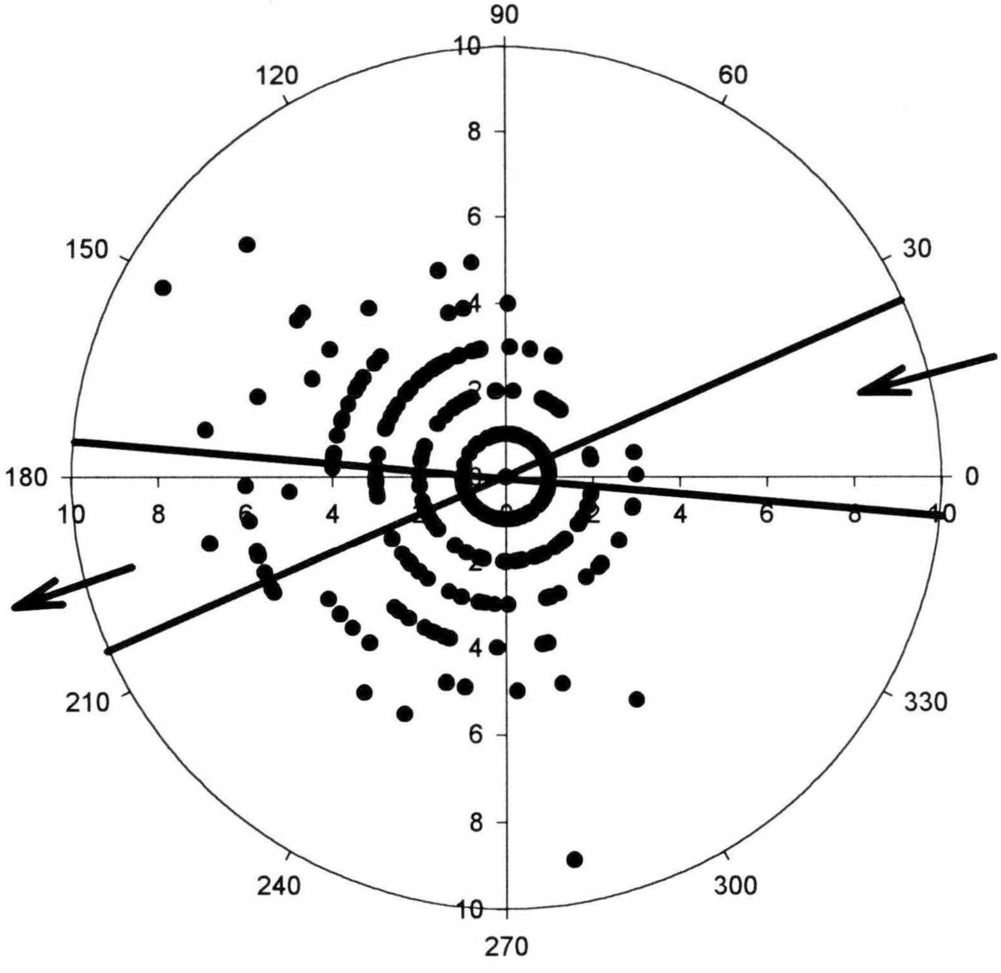


Figure 9c. Polar plot depicting the bearings of seals for the 5th of May. The lines show the bearing range of the currents for that day and their direction of travel.

Seal Bearing for 15 May 1993

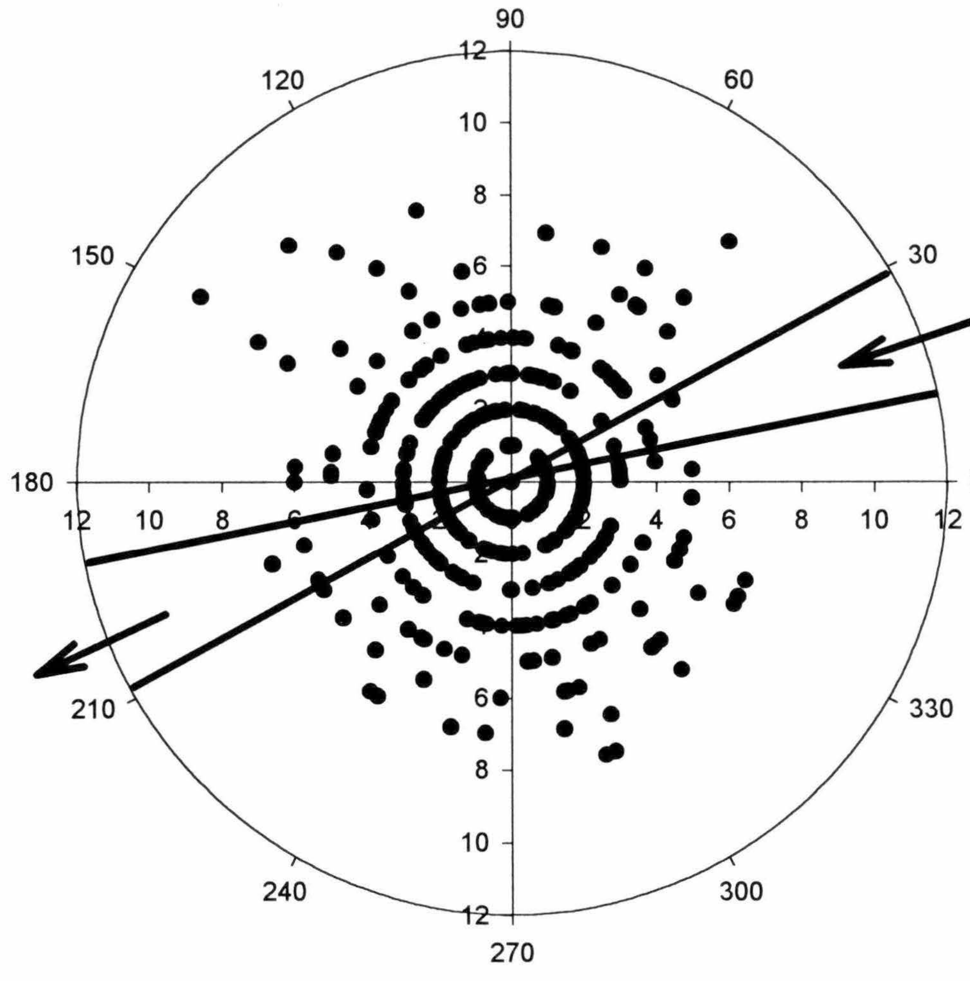


Figure 9d. Polar plot depicting the bearings of seals for the 15th of May. The lines show the bearing range of the currents for that day and their direction of travel.

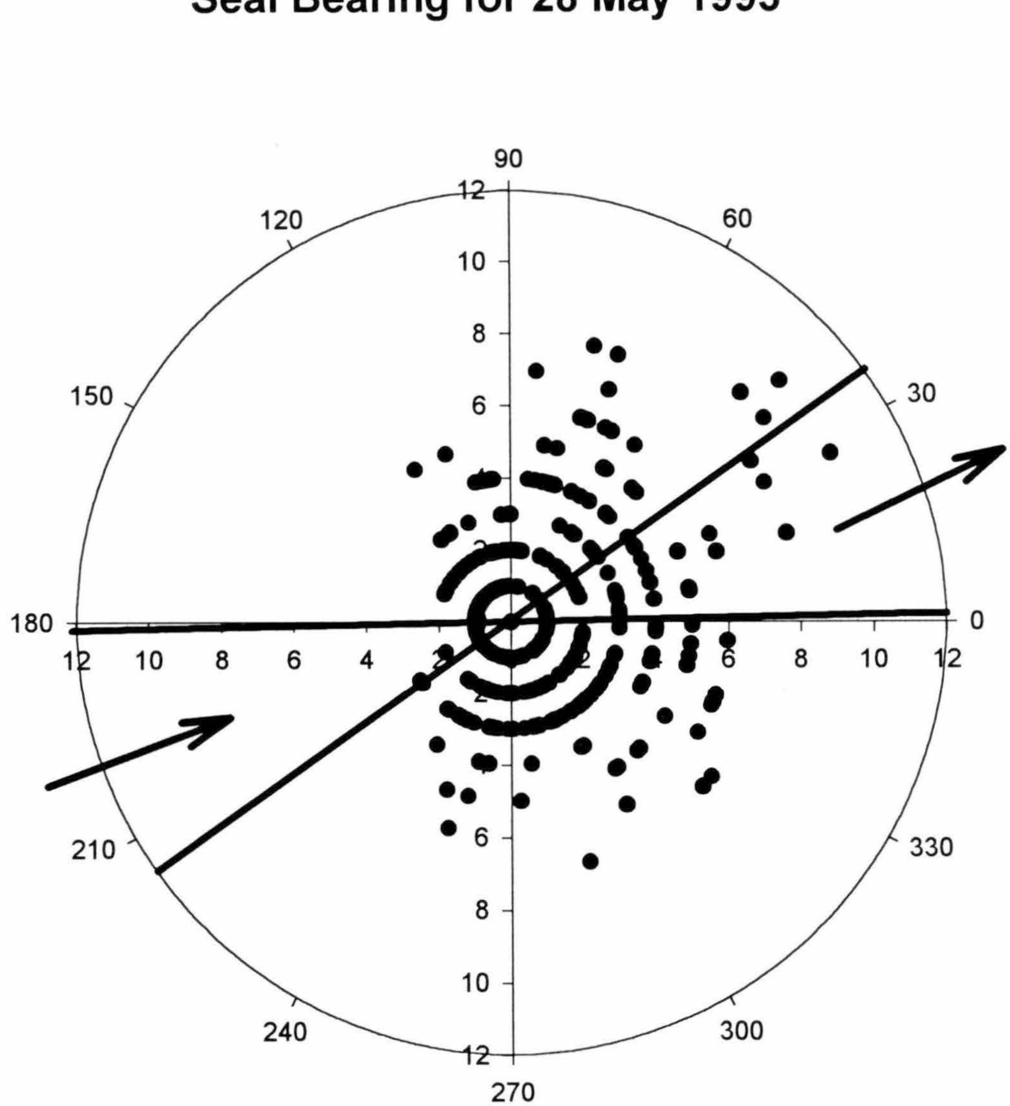


Figure 9e. Polar plot depicting the bearings of seals for the 28th of May. The lines show the bearing range of the currents for that day and their direction of travel.

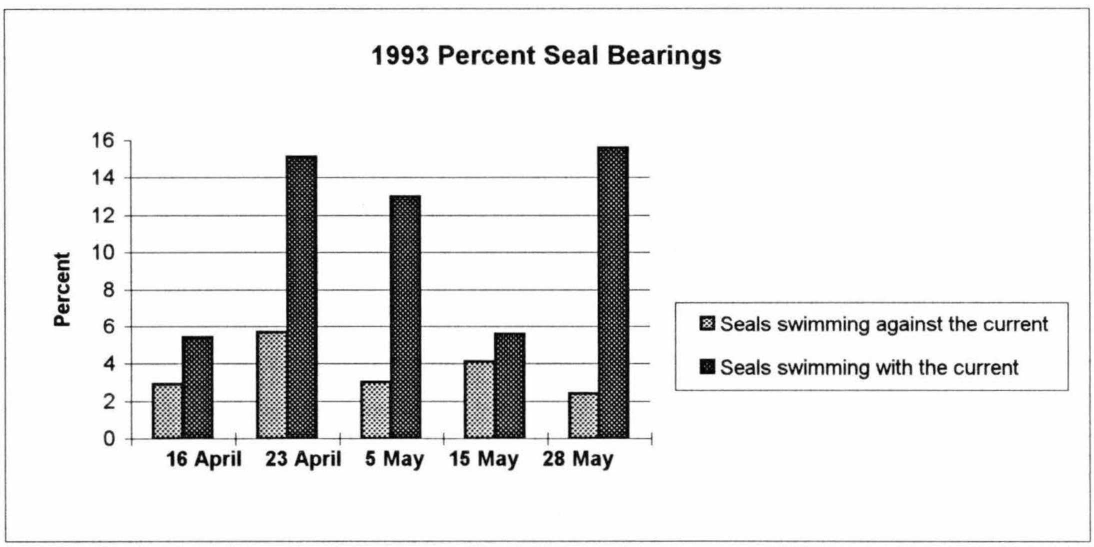


Figure 10. Percent of the seals swimming against the currents compared to the percent of seals swimming with the currents.

CHAPTER 5: MOVEMENT AND DISTRIBUTION

Introduction:

The bearded seal prefers pack ice conditions and relatively shallow water less than 200 m (Burns, 1979). In the spring, the majority of the population off the west coast of Alaska migrates with the ice edge (Burns & Frost, 1979). Migration varies with seasonal ice cover, but usually these animals winter in the Bering Sea and follow the shrinking edge to spend the spring and summer in the Chukchi and Beaufort Seas. This species is very solitary and often widely dispersed throughout the year (Burns & Frost, 1979). However, during the spring a part of the breeding population inhabits the ice leads off Point Barrow, Alaska (Burns & Frost, 1979).

Intense vocal activity of bearded seals occurs during the breeding season and is thought to be associated with breeding activity (Dubrovskii, 1937). Like the Weddell seal, it has been hypothesized that only the adult male bearded seals vocalize (Ray et al., 1969). Further, it is thought that the males hold underwater territories during breeding season and may use vocalizations to maintain these territories and or advertises breeding status to females (Ray et al., 1969). Male bearded seals have been found with deep claw marks along the posterior third of their bodies which may suggest that some form of aggression occurs between individuals (Burns, 1981). Budelsky (1992) suggests a lek or a serial monogamy (polygyny) breeding system. A lek system as exhibited in walrus, in which a large percentage of breeding animals aggregate, does not conform with the solitary nature of the bearded seal (Fay et al., 1984). However, in most lekking species of birds, females are solitary. Perhaps, display behavior in association with territorial defense may take place as part of another form of a lek breeding system in bearded seals. For example, in birds, one population of dunnocks (<u>Prunella</u> <u>modularis</u>) has been found to exhibit an almost complete spectrum of breeding strategies; the variation of available food determines how females distribute themselves spatially, which in turn is a major contributor to the variation of breeding systems of individual birds (Davis and Lundberg, 1984).

The numbers of bearded seals that remain in the Barrow area during the breeding season and their distribution is not known. Aerial surveys have been used to census population size and distribution in the Canadian high arctic (Stirling, Kingsley & Calvert 1982, Heard & Donaldson 1981) and along the coast of Alaska (Burns & Harbo 1972). Abundance in censused areas, during the spring, is roughly less than 1 seal per square kilometer (Burns & Frost, 1979). Acoustic studies on bearded seals (Cleator and Stirling, 1990) were used to measure late winter and early spring abundance by song rates. Budelsky (1992), also studied population size and distribution off Point Barrow Alaska.

The purpose of this section of the thesis was to track bearded seals and to determine their distribution off Barrow, Alaska in the spring of 1993. I used satellite images and visual data logs for the Bowhead whale census to add information to the acoustic data collected. I also studied call rates for diurnal patterns and compared them with Cleator et al. (1989) and Green (1988) who found no late spring cycles. Analysis of tracked seals may lead to an understanding of possible causes of movement including foraging, territorial defense, and search for females. Seal movement and distribution can provide information on seal interactions, and behavioral responses to ice conditions which may lead to a better understanding of the breeding system employed.

Methods:

Methods for data collection and determination of individual seal locations are discussed in Methods Chapters 3 and 4. I calculated distances between seals as follows: It was estimated in Chapter 3 that an average seal could swim 1 km in 10 minutes. I decided to use Budelsky (1992) nearest neighbor minimum value of roughly 1 km and Burns (1981) observation on individual localization of 1 - 3 km radius to establish the 10 minute time period in which to calculate distances. I then selected a seal point and calculated the distances to all other individual seal points falling within the 10 minute interval. The next point in time for a seal location was then taken and distances to other individual seals were again calculated. This continued until all the distances were calculated for each seal point for each seal.

I analyzed and grouped the distances for each seal into the following spacing categories: 0-1000m, 1000-2000m, 2000-5000m, 5000-10000m, 10000-15000m, 15000-20000m, 20000-25000m, 25000-30000m, 30000-40000m, 40000-60000m, resulting in a frequency distribution of spacing for each individual seal. I then grouped and analyzed the frequency distributions of each seal for maximum, minimum and median spacing percentages, resulting in a general qualitative look at spacing for each day. These figures provide data on the “average” seal percent spacing.

After grouping seal distances together for each sample day, I randomly selected 100 distances from each of the 5 days using a Microsoft Excel program, and calculated overall percent seal spacing. Using an ANOVA, I calculated the possibility of significant difference in spacing among the five days. Budelsky (1992) used nearest neighbor equations to determine spacing, but this equation does not take into account the problem of ice conditions skewing the distribution. Nearest neighbor analysis may determine the population is clumped when in fact animals are spaced in an area made smaller by ice conditions that have, for example, limited breathing holes. However, I used the nearest neighbor analysis to compare 1993 data with that of the (1992) Budelsky study. I then obtained satellite images for the Barrow area to correlate with acoustic location plots. Bearded seals tend to prefer flaw zones, leesides of ice floes and leads for breathing holes. These seals have been known to maintain breathing holes in thicker ice, but it is rare. It was estimated that seals can use their heads to break ice up to 5 cm thick (Lowry, pers. comm.). The satellite images were obtained from Alaska SAR Facility (ASF) for visual information on ice conditions. The 1993 Bowhead whale visual log was also used for the above information.

I collected and analyzed seal distances that fell below 2000 m for possible seal interactions. I selected seal movement and interaction examples from two days to provide information on two different types of associations that occurred. These examples were not randomly selected, but I chose those that seemed to represent general patterns or a range of possible associations for this discussion.

Results:

A total of 1240 seals were detected by the analysis in Chapter 4. The breakdown of the number of seals per day is shown below.

Day	Total # of Seals Located	# of Seals Located Only Once	# of Seals Located more Than Once
#1	314	174	140
#2	243	119	124
#3	179	95	84
#4	265	109	156
#5	239	139	100

Figures 11a-e show x-y coordinates for all acoustic seal locations from Carolyn Perch (0,0). In these figures, magnetic north is indicated by an arrow. Figures 12a-e show the daily "average" seal spacing. These plots provide a qualitative look at the typical spacing that occurred for each day. The frequency plots for "average" seal spacing suggest a peak at 10 km during sample days #1, #3, #4 and

#5 and a 15 km peak on day #2. Peaks on days #1 and #3 were near 20 % while days #4 and #5 were near 30 %. The daily total of 10 minute spacings and seal associations are as follows:

Day	# of 10 Minute Spacings	# of Seal Associations
#1	8262	208
#2	5469	237
#3	3350	148
#4	9276	97
#5	5167	75

Percent spacing for all five days, as determined by randomly selecting 100 distances, is shown in Figure 13. Table 7 shows the significance of difference in spacing as determined by ANOVA; F = 7.58064, P = 6.22E-06. Figures 14 & 15 show selected examples of seal movement and interaction. In these figures, individual seals are plotted relative to several other seals. Table 8 provides the movement data for the selected examples. Appendix 1 provides detailed data on the point by point movements of the associated seals. I considered speeds above 5 m/s to be errors and did not consider them in the associations. Also, I considered speeds above 2 m/s to be increased speeds used in interactions, i.e., defense of territory. Generally, seals in all examples traveled or maintained positions as provided in Table 9.

The first example of how the data can be used to determine multi-animal associations is from the 28th of May. Seals #190, #169, #182 and #150 all vocalized in an area of less than 2 km in a short period of time, with three of the calls overlapping one another. All but seal #190 then traveled north, while seal #190 maintained position. From calculated swim velocities, seal #169 may have interacted with seal #182, and seal #190 may have interacted with seal #169. All seals swam across the current and therefore, swim speeds were not influenced by the current.

The second example is from the 23 of April. Seal #7 exhibited a much different type of behavior. This animal traveled 65 km over a 16 hour period. It traveled south and did not make many alterations in general direction. Seal #7 may have interacted with seal #1 over a 2 hour period. Seal #1 did increase speed when in proximity to Seal #1 However, it does not appear that seal #1 changed behavior as exhibited from its maintaining position. Seal #7 may have also interacted with seal #46, but again it does not appear that Seal #46 altered its behavior, as exhibited from its maintaining position. The current may have influenced two swim velocities of Seal #7, when it swam along with the current.

Detailed time, swim velocity, and bearing information is provided in Appendix 2. An example of its use is also provided in the appendix.

Diurnal call rates (Figures 16a-e) show no 24 hour cycle except for the 28th of May. Number of seals per unit time (Figures 17a-e) shows no 24 hour cycle. Figures 18a-e also indicate that no cycle exists in number of calls per seal except for the 28th of May.

Discussion:

The acoustic location x-y plots clearly indicate areas of higher vocalization activity. This suggests that ice conditions or currents may have influenced where the vocalizing seals were located and how they were spaced. Another suggestion for this "clumping" may be the location of females on ice flows. However, there is no information available on the location of females. I obtained satellite images to aid in visualizing ice conditions; however, it was not possible to obtain images during the exact sample days, as the satellites did not pass over the area at those times. Each satellite image was separated in time by a minimum of two days from the corresponding sample day. Also, most images did not provide 100% coverage of the study area. I selected an area of 10 x 20 km near the hydrophone array from each satellite image and acoustic location x-y plots to compare seal locations with ice coverage. The ice conditions observed from the images were not closely correlated to the x-y positions for four of the five sample days. However, ice conditions seemed to remain stable between the 5th of May and the satellite image of the 8th of May 1993. The image indicates areas of leads which correlate with areas of high vocalization. A copy of the satellite image and an overlay of the acoustic data are provided in Appendix 3.

The other satellite images reflect the movement of the ice between the image day and the sample day. Currents and atmospheric conditions could have altered the ice configurations to match those indicated by acoustic location x-y plots on the sample days. Visual and current logs kept during the 1993 census indicate that currents were slower after the 5th of May and at one point reversed. This may have resulted in the ice conditions remaining roughly the same when the image was taken on the 8th of May. The currents of the 21st and the 24th of April did not show marked change in direction or speed; however, currents on 10th and the 26th of May did show marked changes in bearing and speed.

ANOVA determined the 100 randomly selected distances from each day to be significantly different among sample days. Ice conditions may have contributed to the changes in seal distribution. The frequency distribution of these randomly selected spacings also show a marked peak at 5 - 10 km. Day #2 showed a higher peak at 10 - 15 km. It could be a reflection of currents, ice conditions and or a change in breeding strategies. As ice conditions changed, the breathing areas, leads and pack ice, also changed, and the seals may have redistributed themselves accordingly. Also, ice floes containing females may have moved faster or slower, changed direction and thus altered male movements and spacing. Confrontations between males may occur if changes are rapid due to greater sea currents and atmospheric activity. The peaks at 5 - 10 and 10 - 15 km may also be a result of some seals vocalizing more than others. Seals that called more frequently may have provided more data points and distances in these categories.

A Chi-test of the nearest neighbor equation for each day determined that spacing was not significantly different from random. However, due to problems discussed above, ice conditions may not have been entered into the evaluation and analysis of spacing. Unfortunately, due to various factors including limited image coverage, it is not possible to calculate seal spacing relative to breathing areas.

The two example plots of seal movements (Figures 14a and b and 15a and b) show various types of movement. Associations between seals in the examples provided may indicate several forms of behavior. It is possible that there was a multi-confrontation between the seals on the 28th of May, that resulted in them continuing the associations north. Seal #190 may have succeeded in defending the territory or female while the others left the area. Or, the three northbound seals may have pursued a female after displaying. It has been hypothesized that animals may "mask" or vocally duel one another during the breeding season to obtain mating privileges with females and preferred territories (Kroodsma, 1979). Male Hyla ebraccata, a species of frog, are known to mask rival calls during the breeding season, supporting the hypothesis that calls are timed to reduce the effectiveness of competitor calls while increasing the individuals' chances of attracting a mate (Wells and Schwartz, 1984). There might have been an interaction near a female on an ice floe, in which the males were trying to compete by displaying together. Because of the assumptions made during the initial separation of locations into individual seals, seals displaying in a lek would not be detected unless their vocalizations overlapped. Individual seals displaying together in the same area and sequentially vocalizing could not be detected, and therefore were called the same seal. The overlapping calls in this instance suggest a lek system may be employed by the bearded seal.

Seal #7 on the 23rd of April exhibited a much different type of behavior (Figures 14b and 15b). This animal traveled 65 km over a 16 hour period, while the other nine seals maintained their respective positions. It traveled south across the current and did not make many alterations in general direction. This seal may have been foraging, in transit in the local area, or looking for a female on an ice floe. Some interactions may have occurred with two other seals, but they maintained positions. It does not appear that any defensive behavior took place with the other seven seals.

Cleator et al. (1989) documented a late winter diurnal cycle which began to break down towards the end of May. No diurnal cycle was found in this study until the 28th of May. I am not sure why no initial cycle was found, or why a cycle is found in late May. It does appear that the number of calls per seal, as seen in Figure 18 for the 28th of May, may have influenced the cycle. Green (1988) provided data on the association of number of seals in the water and vocalization rates. The data did not specifically indicate a diurnal cycle in late spring. The lack of a cycle in this study may have to do with increasing sun time, weather and availability of more females after pupping (Green, 1988). In collecting the data, I observed that some seals called more frequently than others. There was no pattern to this observation, but perhaps it may be that males in better condition vocalized more frequently.

This study provided an example of the usefulness of acoustics in determining seal abundance, distribution with respect to ice conditions, and spacing. Also, the acoustic data provided the ability to track bearded seal movements relative to each other and to geographic and oceanographic features. Improvements in satellite imaging technology, including enhanced images and programs that are better able to classify ice, will provide much needed visual information. Also, new satellite programs, currently being developed, will allow the researcher to see the temporal growth, disintegration and distribution change of leads and ice floes. Correlations between acoustic and satellite data will provide distribution and spacing information. It may also provide information on likely areas of female-pup locations on ice floes.

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Table 7. ANOVA of significance of difference in seal spacing between sample days.

ANOVA: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	100	938816.8	9388.168	36259229
Column 2	100	1150342	11503.42	38239242
Column 3	100	1169698	11696.98	39663683
Column 4	100	884764.1	8847.641	32809138
Column 5	100	800396.7	8003.967	30516188

ANOVA

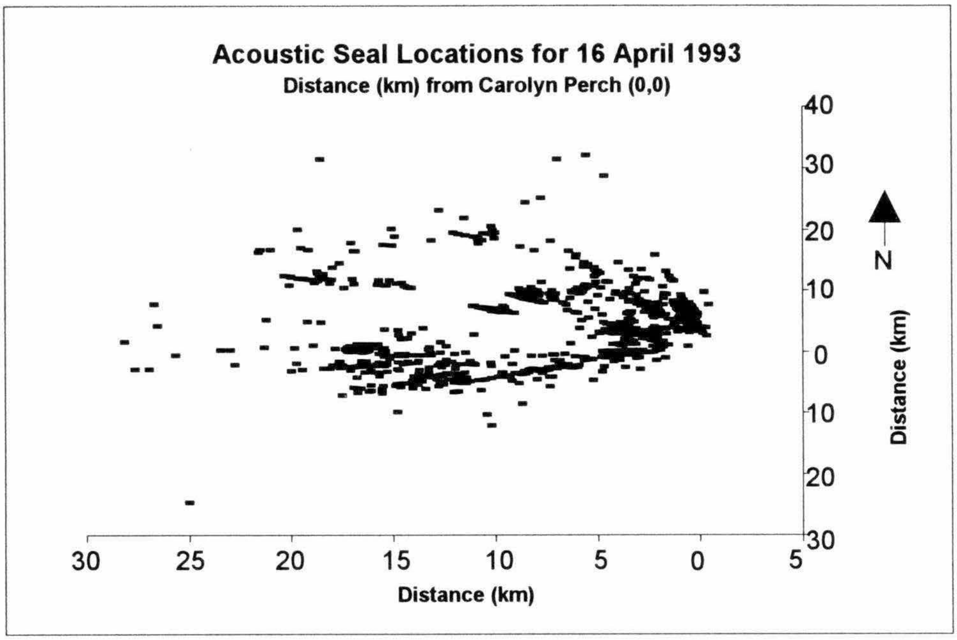
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.08E+09	4	2.69E+08	7.58064	6.22E-06	2.389946
Within Groups	1.76E+10	495	35497496			
Total	1.86E+10	499				

Table 8. Movement data for seal track examples.

23 April	Area (km^2)	Total Time	Distance Traveled (km)	Mean Velocity (m/s)
Track #7	33.49	16:31:28	65.47	2.8
Track #12	0.002	0:33:07	0.09	0.04
Track #1	0.41	4:24:39	3.52	1.1
Track #46	0.06	0:15:26	0.95	1.2
Track #148	1.08	1:21:38	2.48	1.6
Track #162	0.26	1:01:11	1.19	0.3
Track #165	0.56	0:50:47	2	3.6
28 May	**Area (km^2)**	**Total Time**	**Distance Traveled (km)**	**Mean Velocity (m/s)**
Track #190	0.13	0:33:57	1.38	1.6
Track #169	8.07	4:02:53	11.09	1.8
Track #182	0.69	1:10:40	2.32	5.9
Track #150	0.88	1:53:06	2.81	0.6

Table 9. Direction of travel data for seal associations

Day	Seal #	General Direction of Travel	Number of Locations
23 Apr.	7	South	292
	12	Maintained Location	2
	1	South	29
	10	Located only Once	1
	46	Maintained Location	10
	148	Southeast	13
	118	Located only Once	1
	153	Located only Once	1
	162	Maintained Location	3
	165	Maintained Location	4
28 May	190	Maintained Location	4
	169	North	46
	182	North	8
	150	North	10



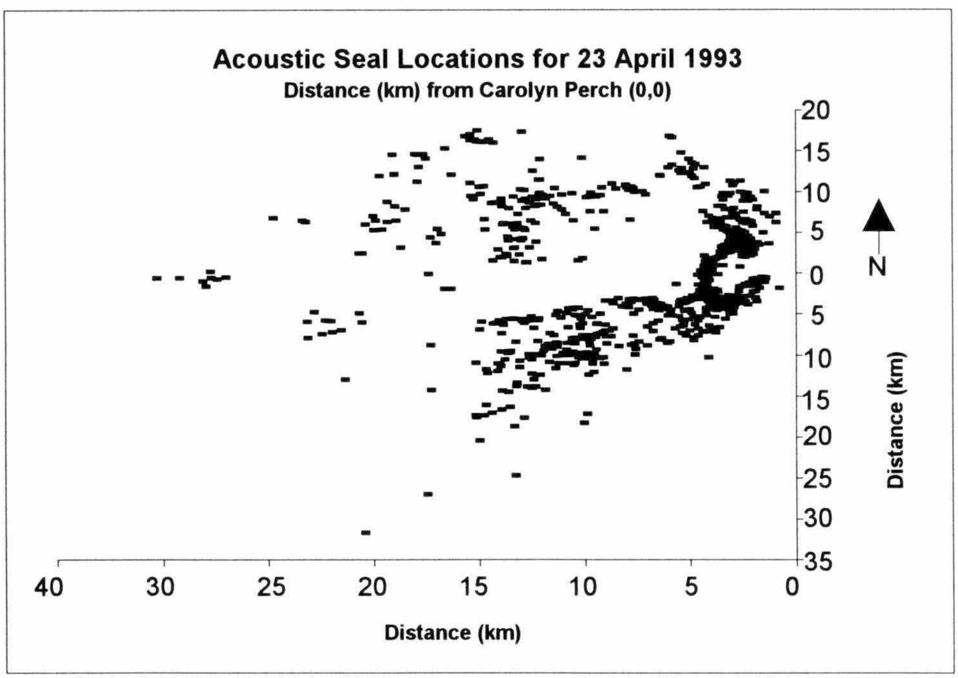
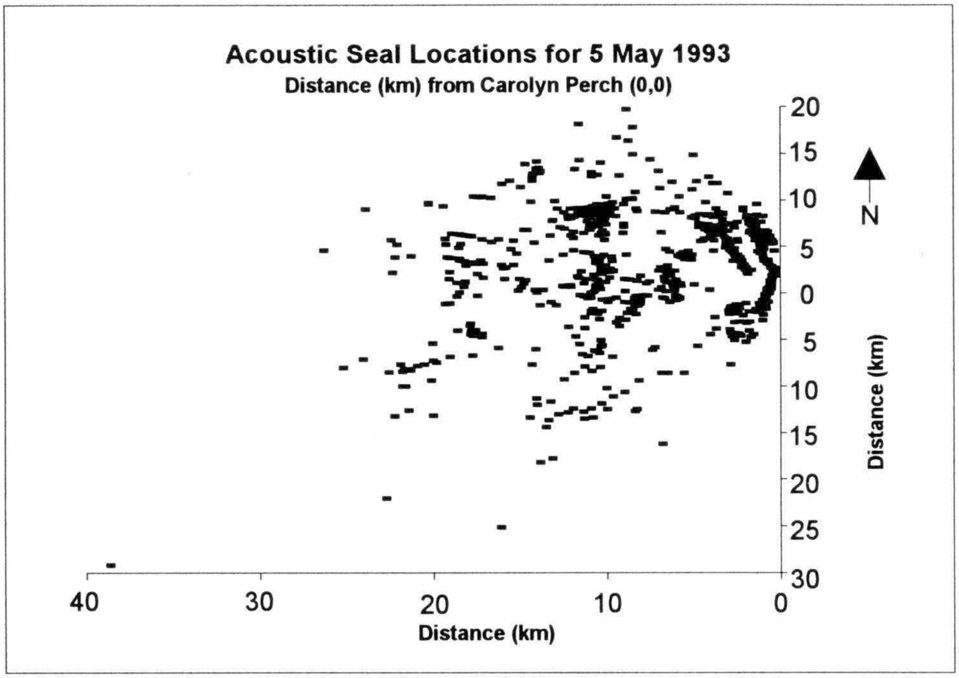


Figure 11 a and b. Acoustic locations plotted from Carolyn Perch.



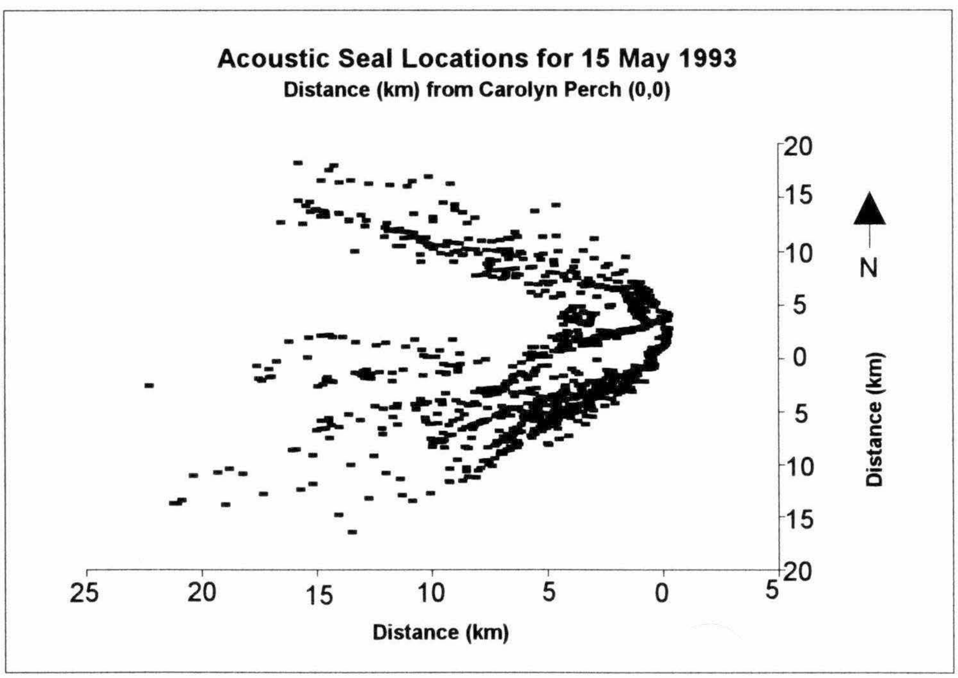


Figure 11 c and d. Acoustic locations plotted from Carolyn Perch.

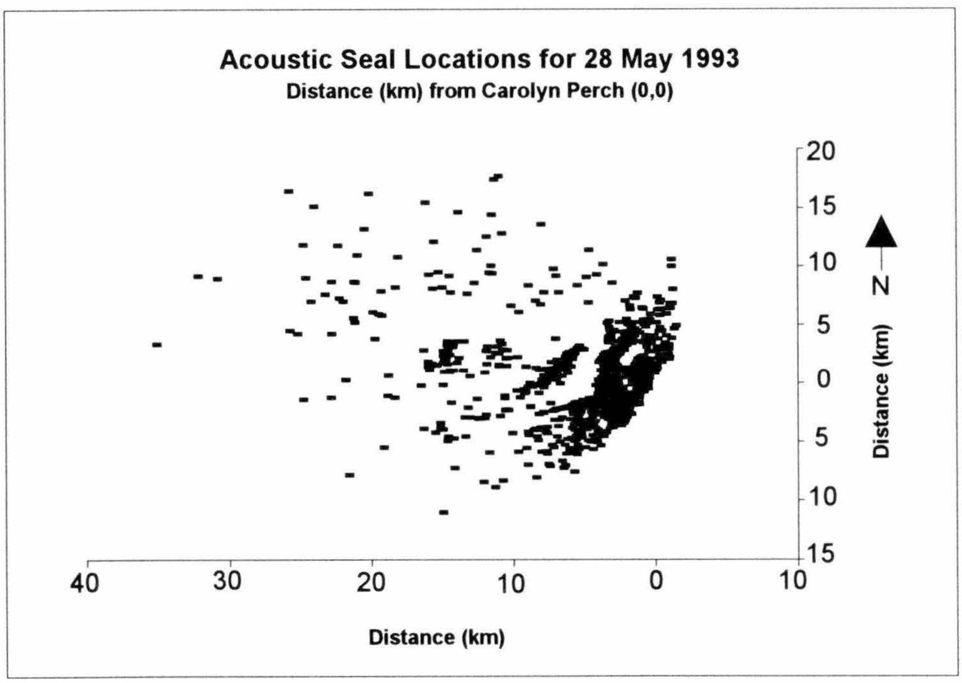
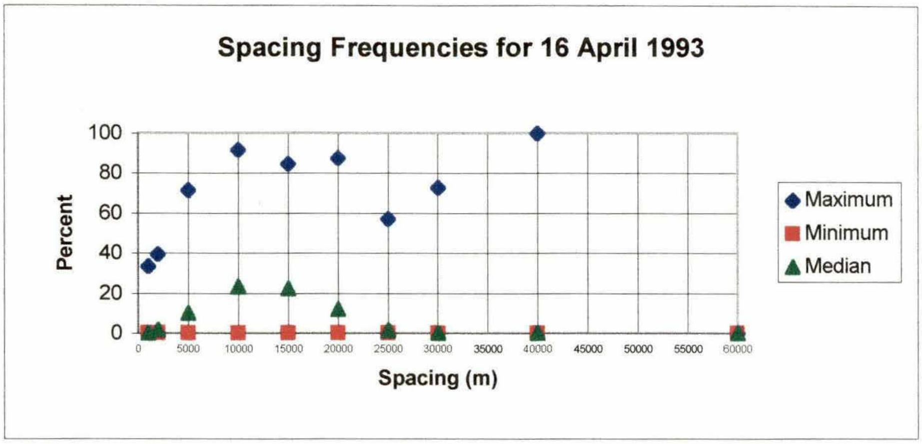
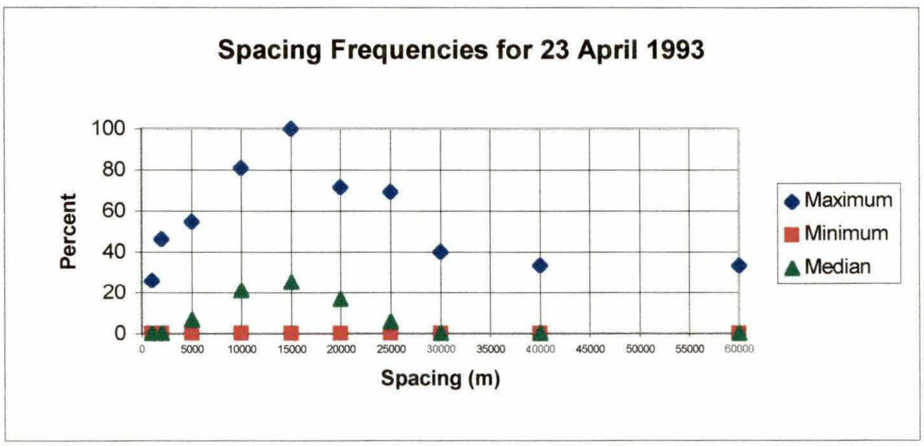


Figure 11e. Acoustic locations plotted from Carolyn Perch.





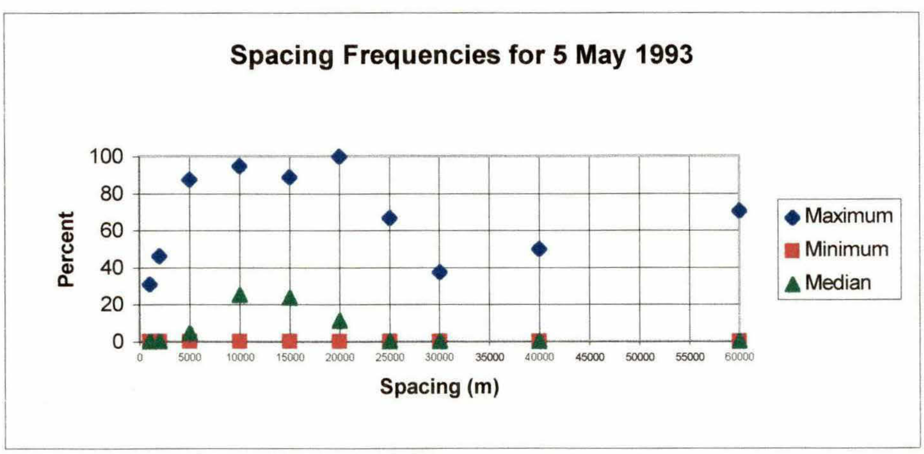
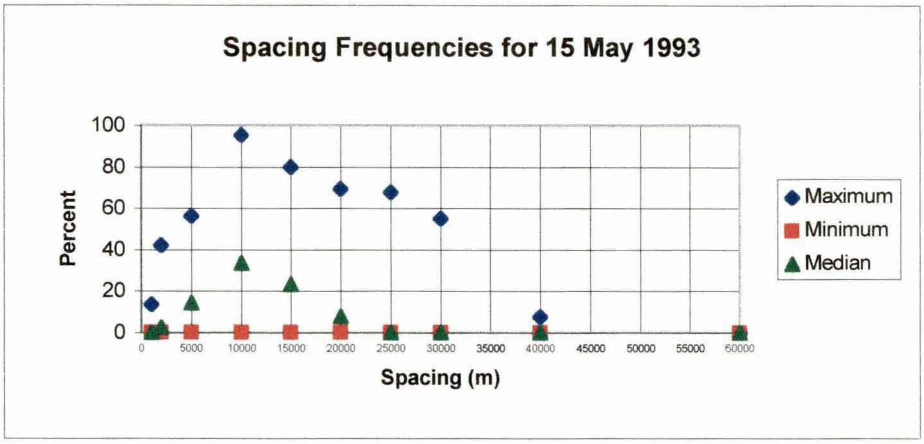


Figure 12(a-c). Maximum and minimum values for frequency distribution of seal distances. Median values give the "average" seal distance for each category.



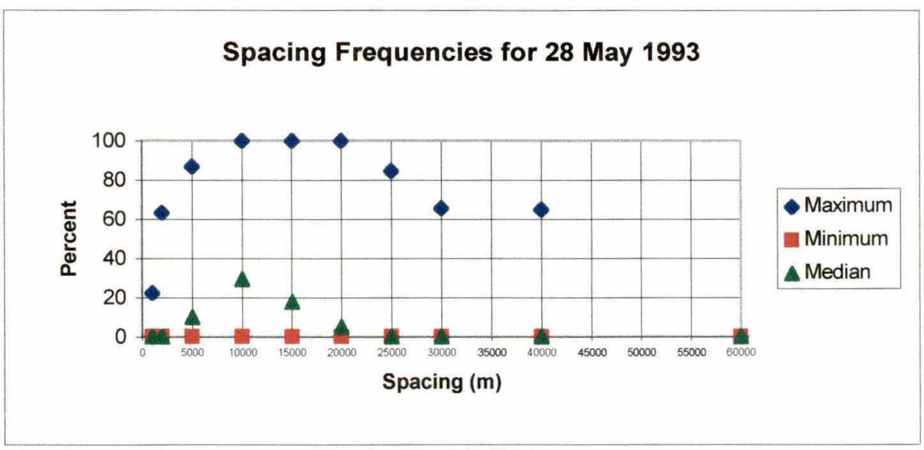


Figure 12(d and e). Maximum and minimum values for frequency distribution of seal distances. Median values give the "average" seal distance for each category.

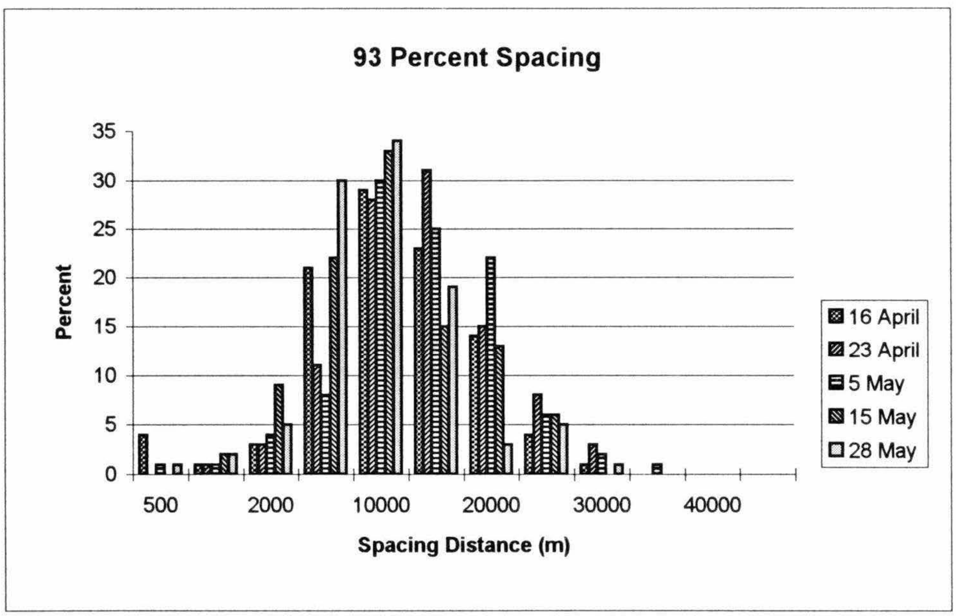


Figure 13. 1993 Frequency distribution for 100 randomly selected seal distances.

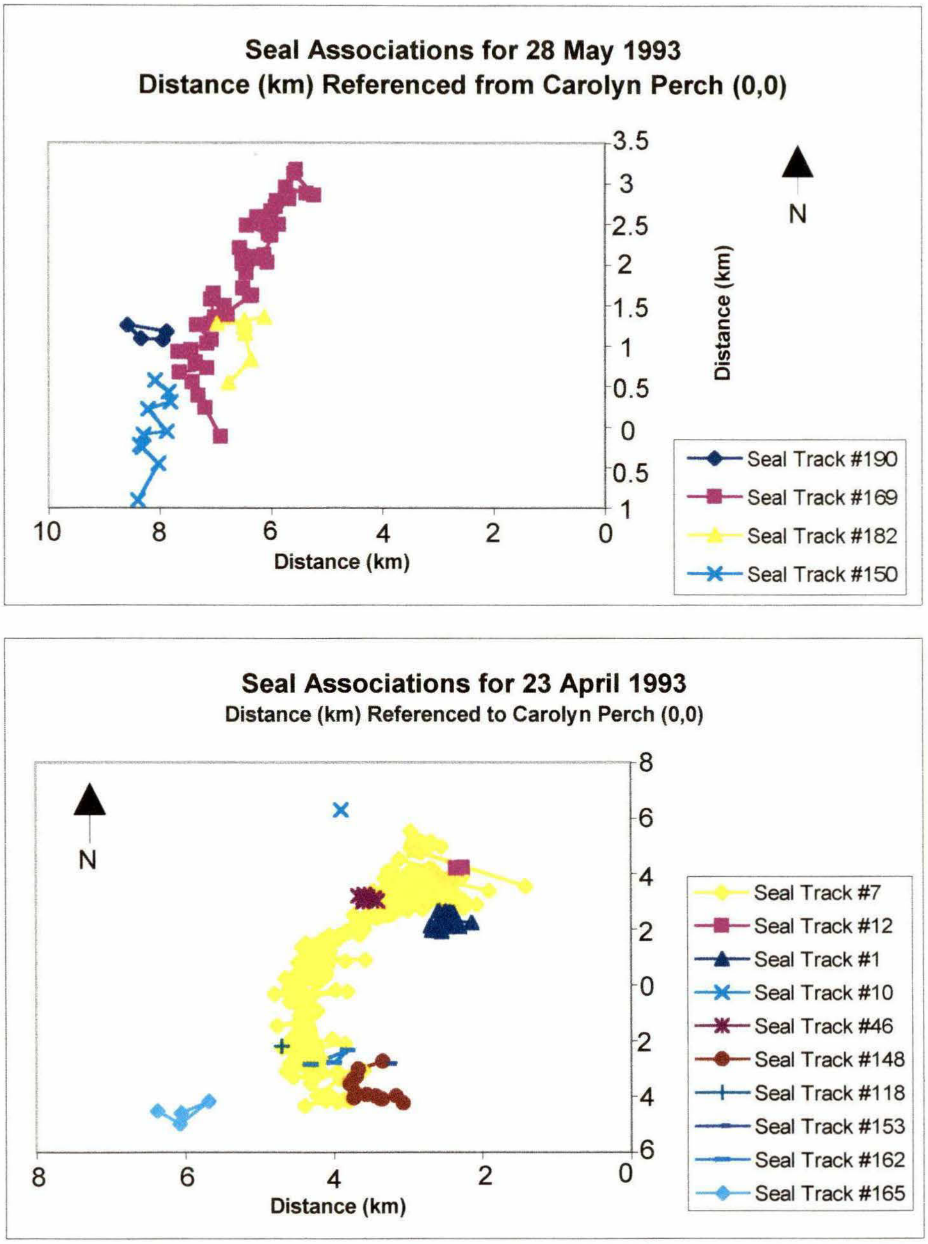
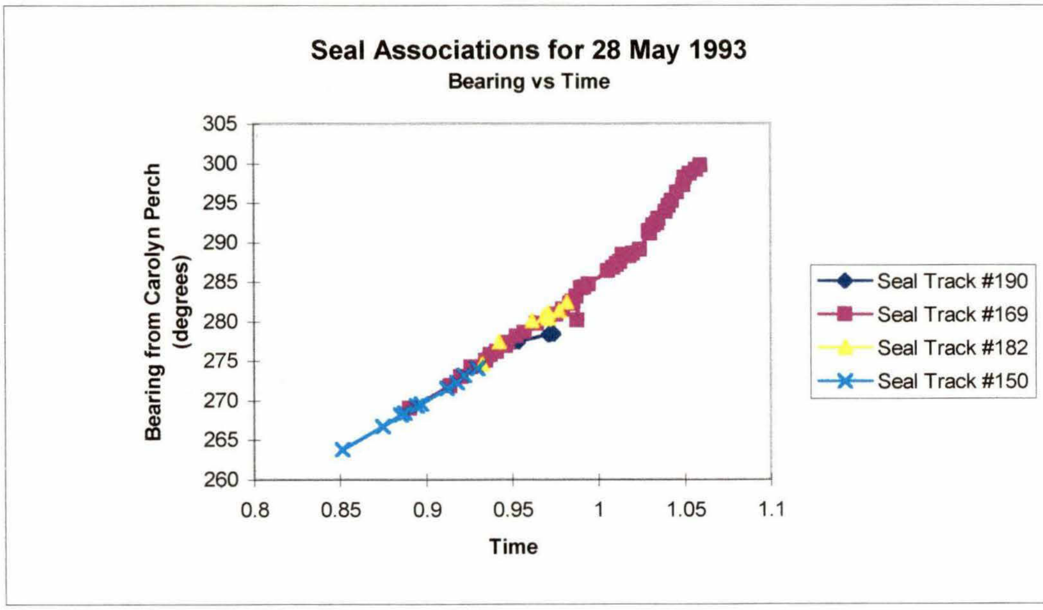


Figure 14 (a and b). Movements and associations of tracked seals. Seals were tracked from Carolyn Perch. Note that some seals moved over a greater distance, when compared to seals that remained in their respective areas.



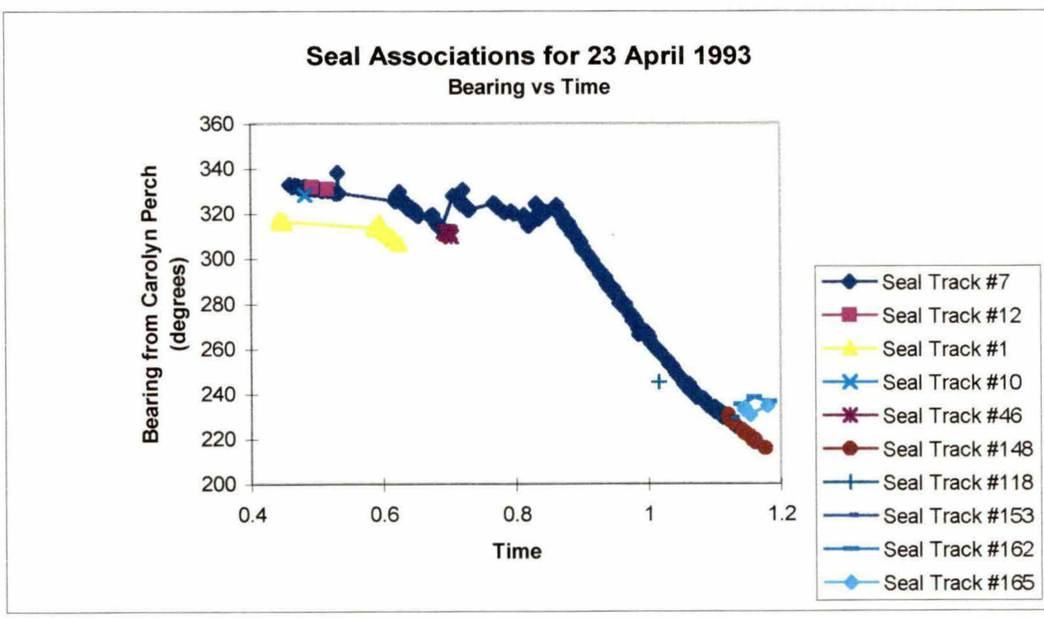


Figure 15 (a and b). Bearing movements and associations of tracked seals. Bearings are from Carolyn Perch. These bearing plots depict the same seals found in Figure 8 (a and b). Distances from Carolyn Perch are not shown here.

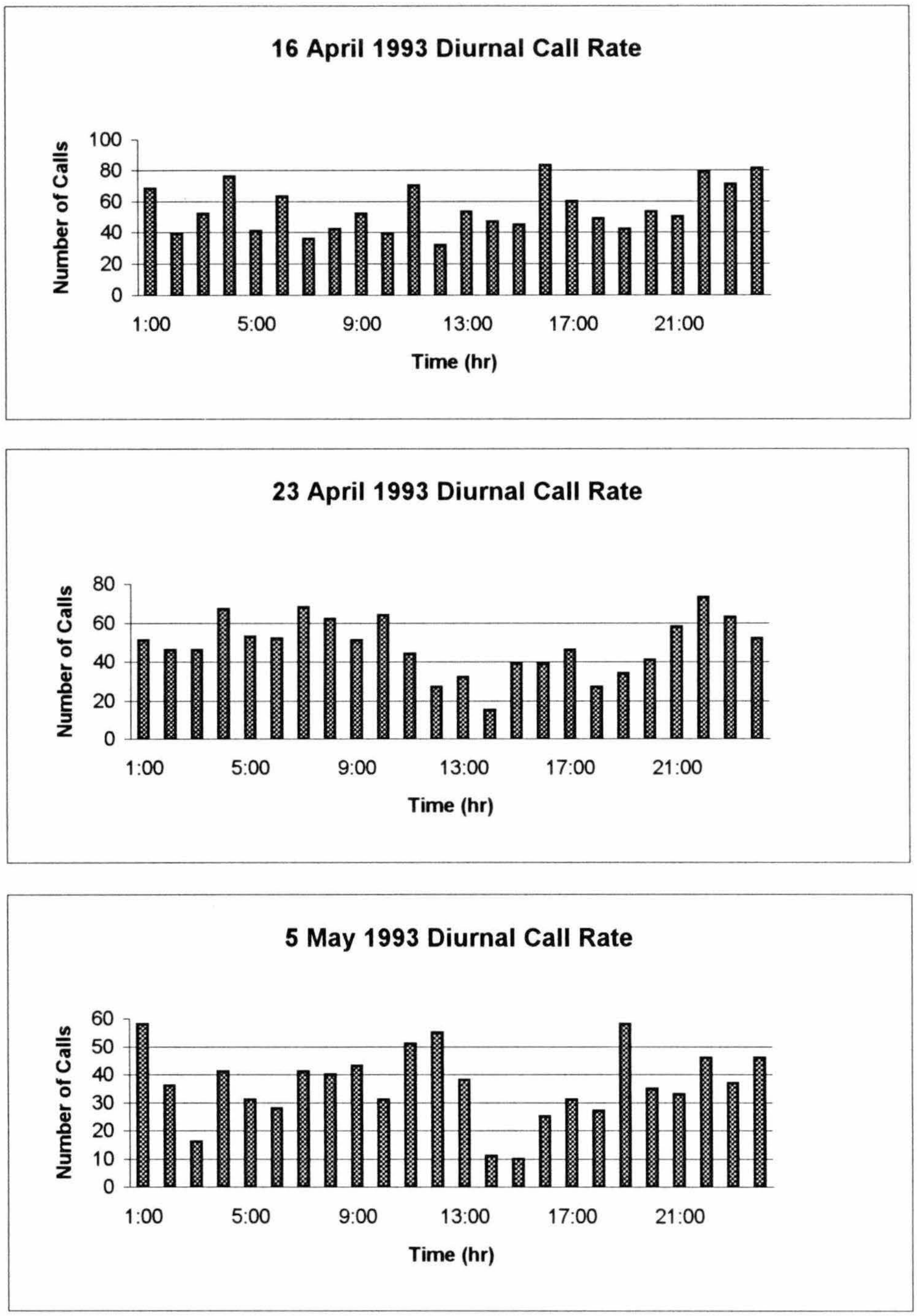
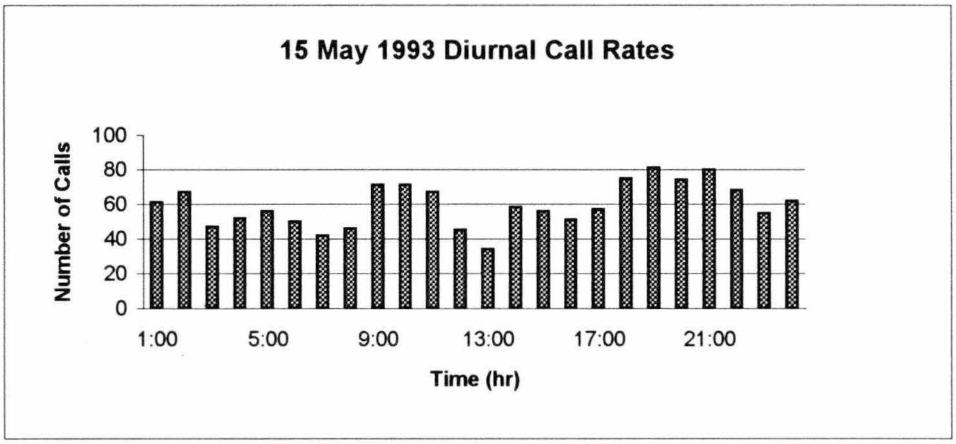


Figure 16 (a - c). Diurnal call rates. Note, there does not appear to be any diurnal cycle. Time is Alaska Daylight Time (ADT) for the 16th and 23rd of April and Alaska Savings Time (AST) for the 5th of May.



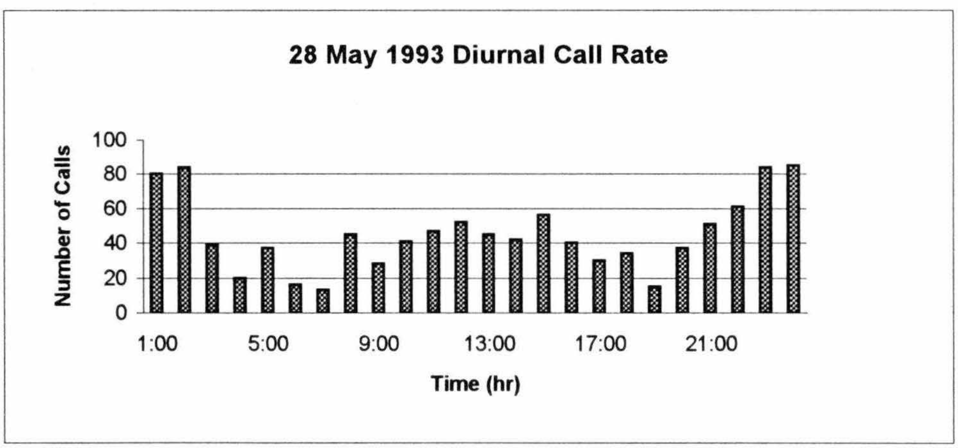


Figure 16 (d and e). Diurnal call rates. Note, there does not appear to be any diurnal cycle on the 15th of May, but there does appear to be a diurnal cycle on the 28th of May. Time is AST.

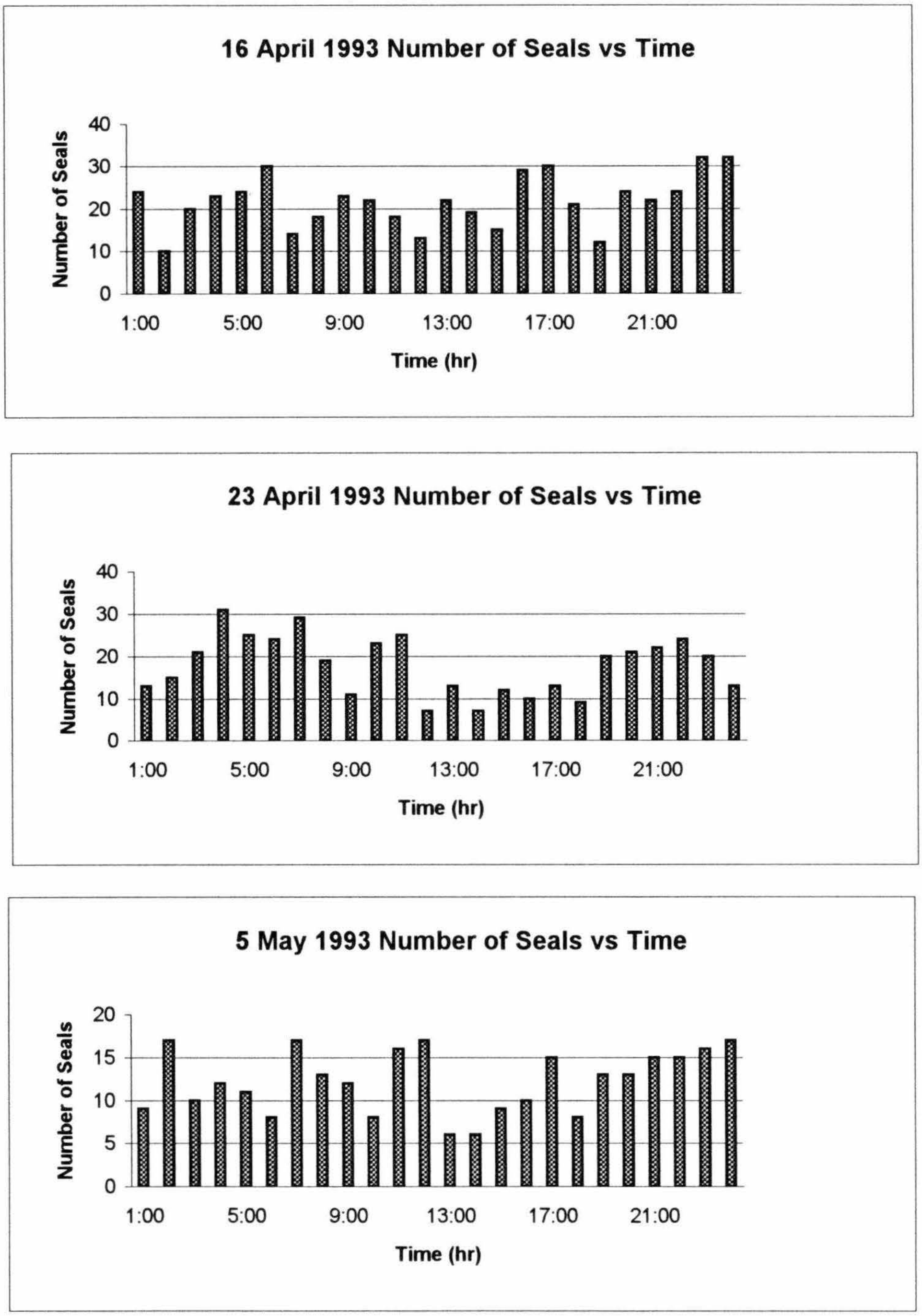
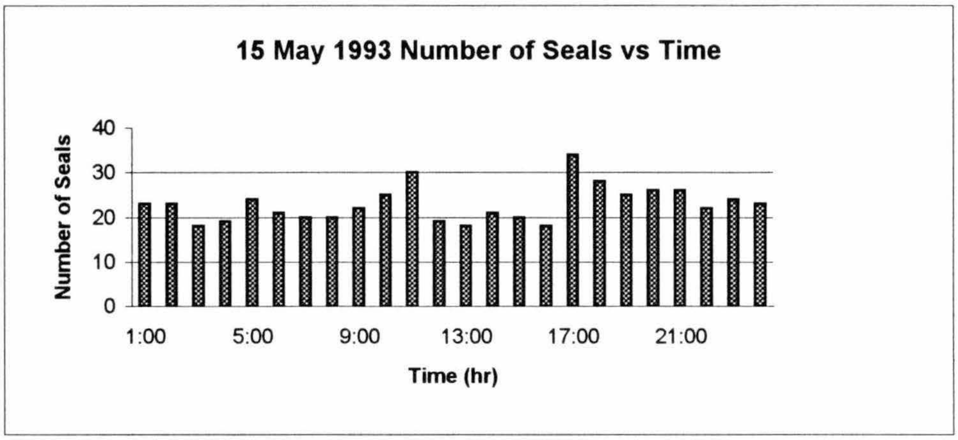


Figure 17 (a - c). Number of seals over the course of the sample day as determined by grouping the acoustic locations into individual seals. Time is ADT for the 16th and 23rd of April and AST for the 5th of May.



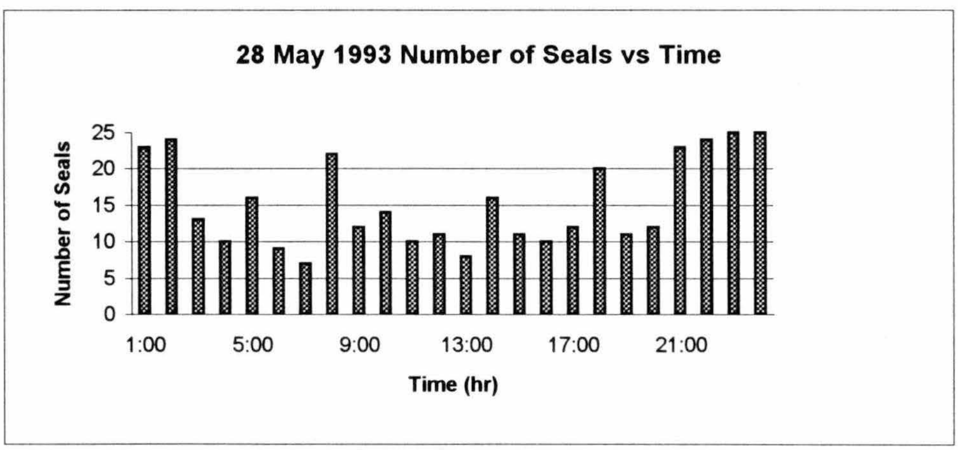


Figure 17 (d and e). Number of seals over the course of the sample day as determined by grouping the acoustic locations into individual seals. Time is AST.

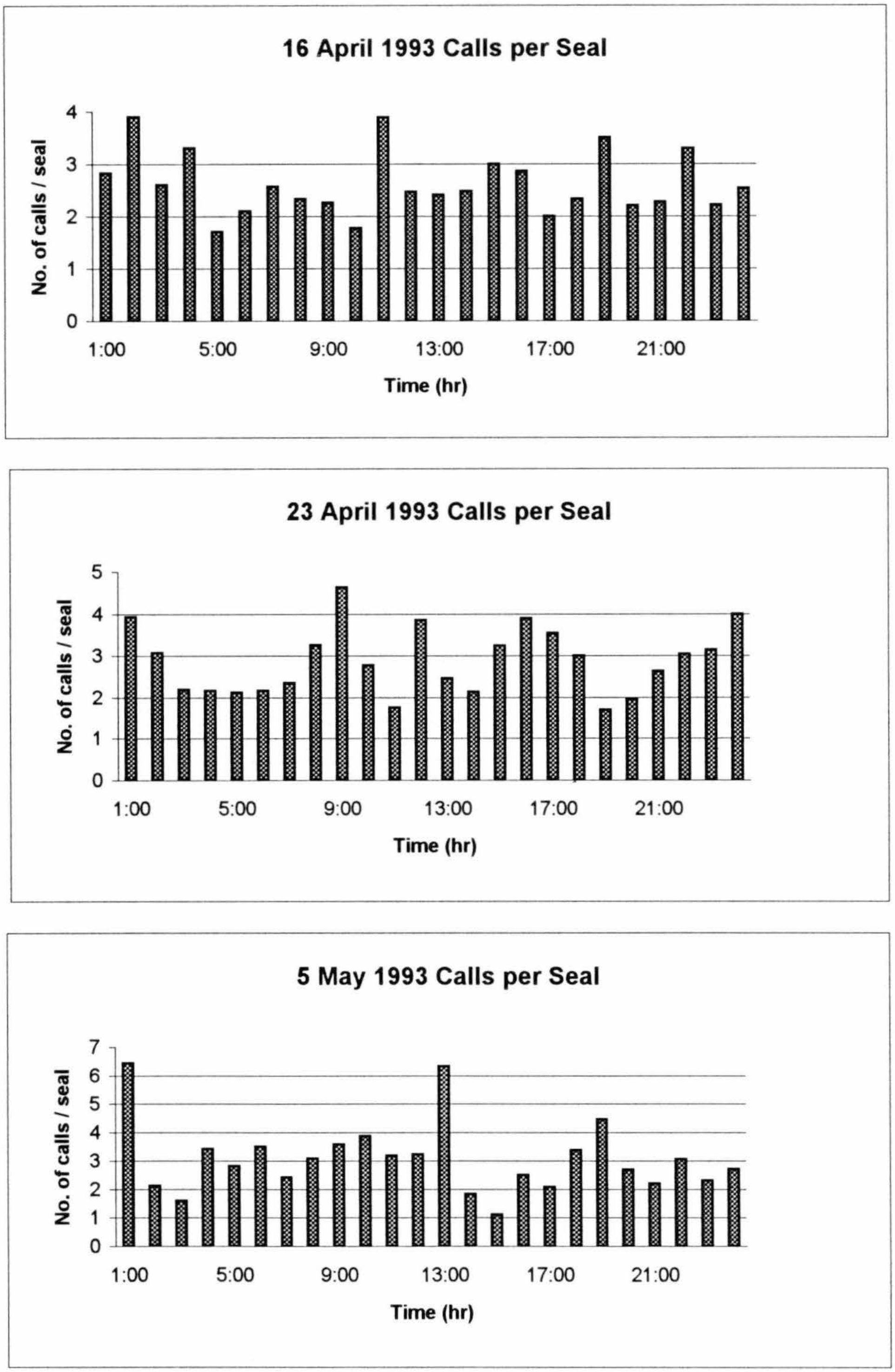
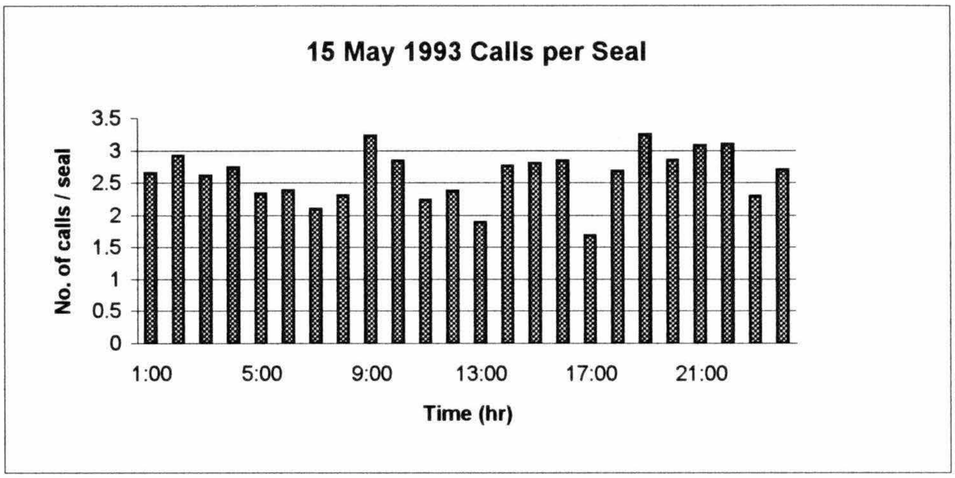


Figure 18 (a - c). Number of calls per seal. Call rates varied between some seals. Again, individual seals were determined from grouping acoustic locations. Time is ADT for the 16th and 23rd of April and AST for 5 May.



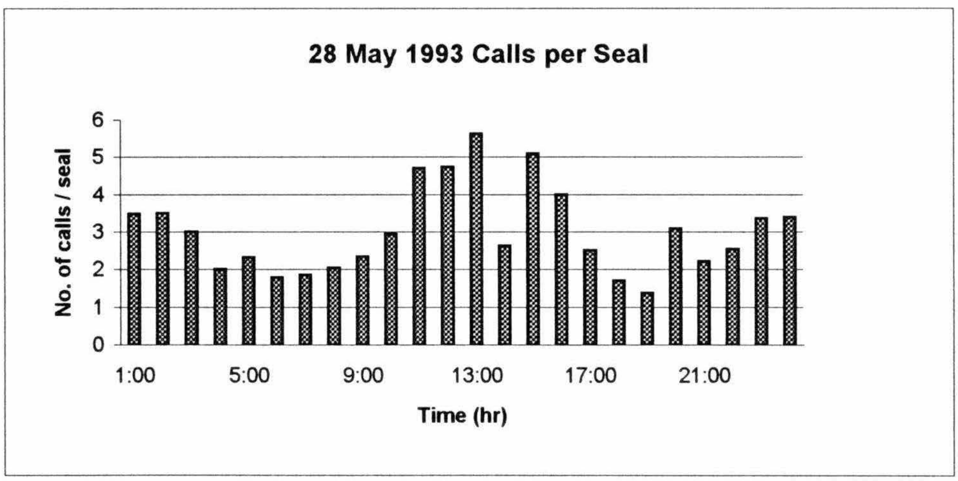


Figure 18 (d and e). Number of calls per seal. Call rates varied between some seals. Again, individual seals were determined by grouping acoustic locations. Time is AST.

CHAPTER 6: MULTIPATH

Introduction:

A signal produced underwater will travel in many different paths using different angles (Figure 19). Urick (1983) describes acoustic multipath propagation in water as occurring whenever there is more than one propagation path between source and receiver. Multipath occurs most commonly in ducted propagation situations such as when there are both surface water and deep ocean ducts. When the source is in motion, multipaths that carry similar amounts of energy may also vary in phase and amplitude. Multipath situations can cause fluctuations in phase and amplitude at a single receiver, signal distortion due to different travel times of different paths, decorrelation of phase and amplitude between separate receivers, degradation of array gains, and frequency broadening (Urick, 1983). Basically, if multipath conditions are a factor, the received signal may not reflect the true characteristics of the source signal and thus may distort triangulation data by producing a false location. The degree of location error will depend on the multipath conditions, which are random.

As indicated earlier, multipaths may occur when the source, in this case, a seal, is in motion. Burns (1981) reported repetitive spiral diving by seals in association with vocalizations. The constant change in direction of propagation would significantly impact the reception of the signal. Also, different calls may have different source signals which would further complicate the tracking of an individual seal. Furthermore, ice conditions and the shelf bottom may also cause multipaths. One signal may bounce off the ice or bottom at different angles resulting in various signals that are received at different times.

The purpose of this chapter is to provide an example of multipath in a single descending trill call. I selected four sections of the same call for locating the same seal. It is important to consider this problem since it is a significant factor in tracking individual seals and because its effects are random.

Methods:

I selected four parts, all frequency modulated, of a single descending trill from the analyzed tapes. Locations were calculated as described in the methods chapter. I then presented the differences in locations and bearings from Carolyn Perch as an example of multipath distortion.

Results:

Figure 20 shows the coordinates of the four calculated locations for the single trill from Carolyn Perch. Figure 21 shows the differences in computed distances from Carolyn Perch. Figure 22 shows the differences in bearing from Carolyn Perch plotted against time of day.

The four parts of the single call were separated in time by 9 seconds. They ranged from 4240.9 m - 3833.17 m and a bearing of 329.986° - 328.834° from Carolyn Perch.

LocID	Date	Time	XLoc	YLoc	Range	Bearing
52812018	5/27/89	23:52:09	-2209.28	3619.99	4240.9	328.60
52812019	5/27/89	23:52:11	-2151.99	3558.15	4158.31	328.83
52812020	5/27/89	23:52:14	-1917.4	3319.15	3833.17	329.99
52812021	5/27/89	23:52:18	-2123	3539.35	4127.25	329.04

Distances between the four locations are as follows:

Location	Distance (m)	Time (s)
Location 1 & Location 2	84.3	2
Location 1 & Location 3	419.2	5
Location 1 & Location 4	118.1	9
Location 2 & Location 3	334.9	3
Location 2 & Location 4	34.6	7
Location 3 & Location 4	301.3	4

Discussion:

A maximum distance of 419.2 m separated two parts, only 5 seconds apart, of the same call. The swim velocity values from Chapter 2 found that the majority of swim speeds for bearded seals fell between 0 - 1 m/s. A velocity of 419.2 m / 5 seconds (83.8 m/s) vastly surpasses this average. The data suggest that multipath was a factor in this instance and that it affected the four locations differently in a very short time period. This also suggests that multipath could have been a factor throughout this study and may explain some of the elevated calculated swim speeds including the 10% above 5 m/s. It also may have been a factor in the tracking of seals in Chapter 4, but the degree of error is not known. Multipath is a very important factor in acoustic research and future efforts should be made to determine some type of constant error correction value to be entered into triangulation equations.

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Urick, R.J. 1983. Principles of Underwater Sound. McGraw-Hill Book Company. 193-194.

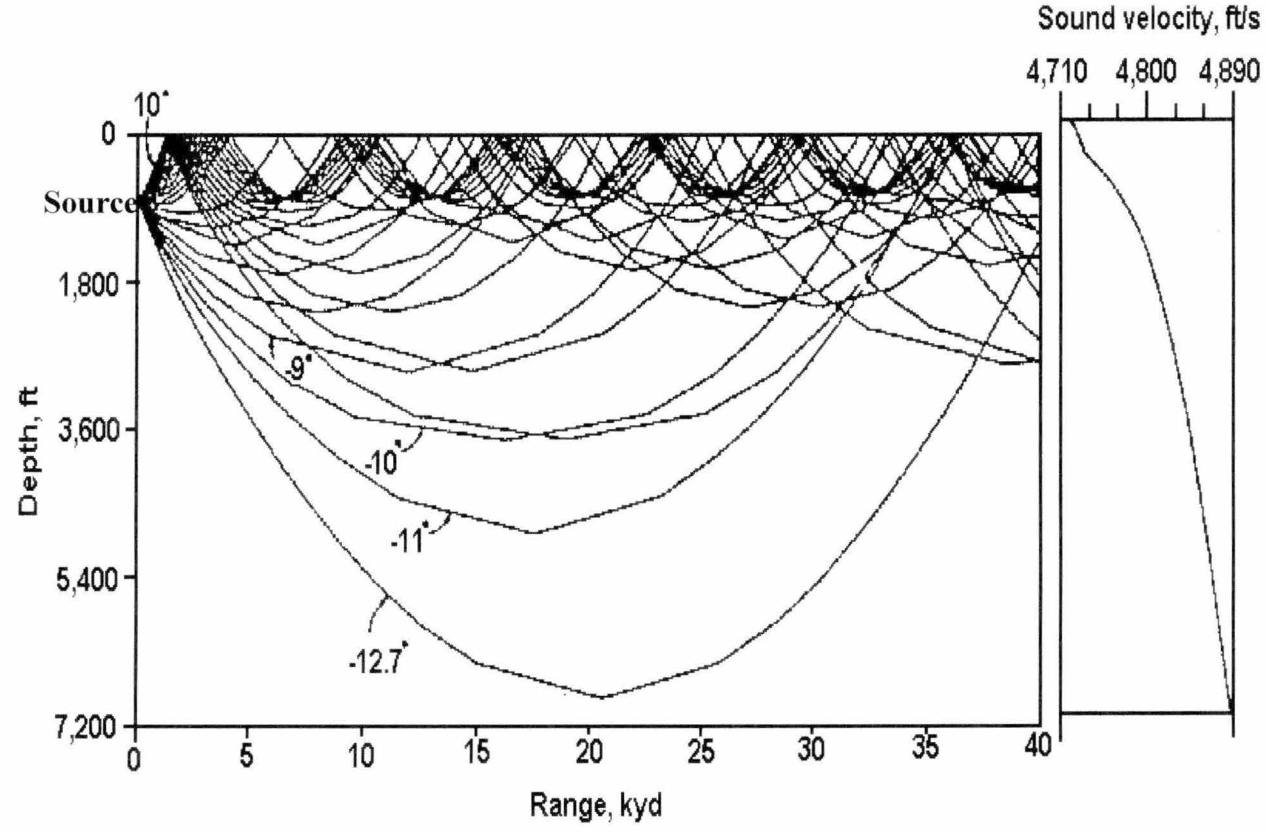

Figure 19. This is an example of the various paths of one signal. The source, or seal, produces a signal and it travels to the receiver, or hydrophone, by various paths and angles. The figure is from Urick, 1983.

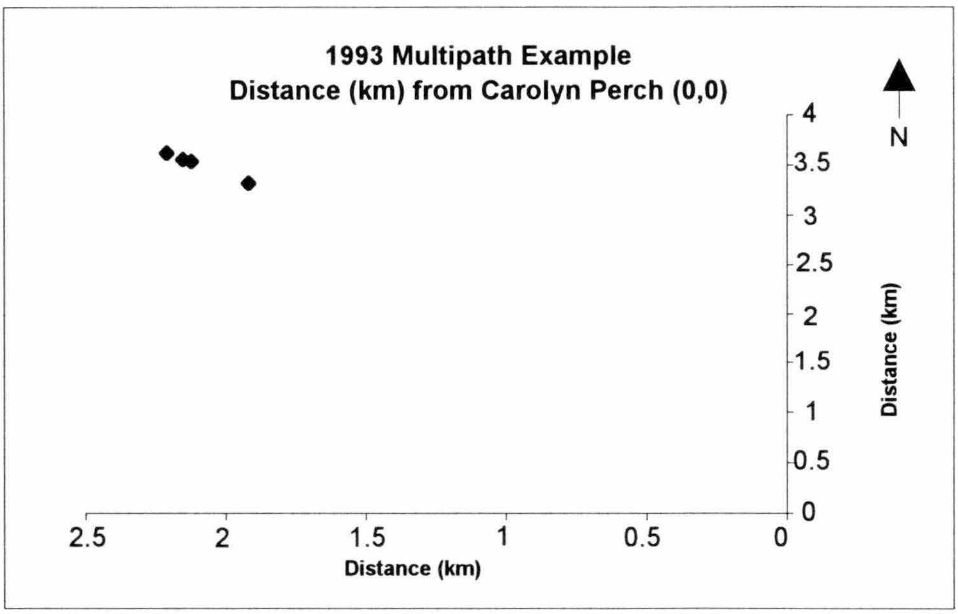

Figure 20. Acoustic locations of the four parts of the descending trill call plotted from Carolyn Perch.

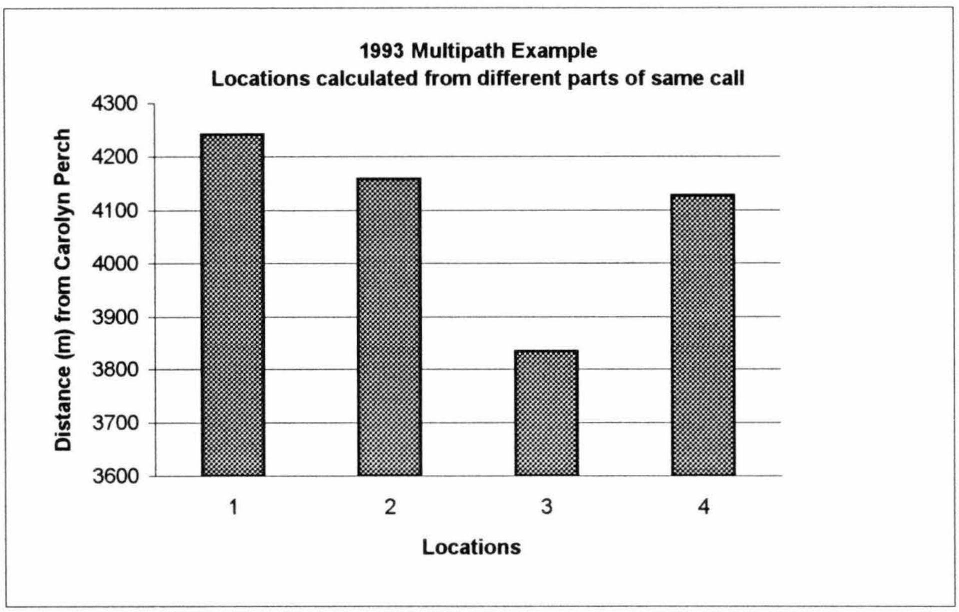

Figure 21. Distances of locations of the four parts of the descending trill call plotted from Carolyn Perch.

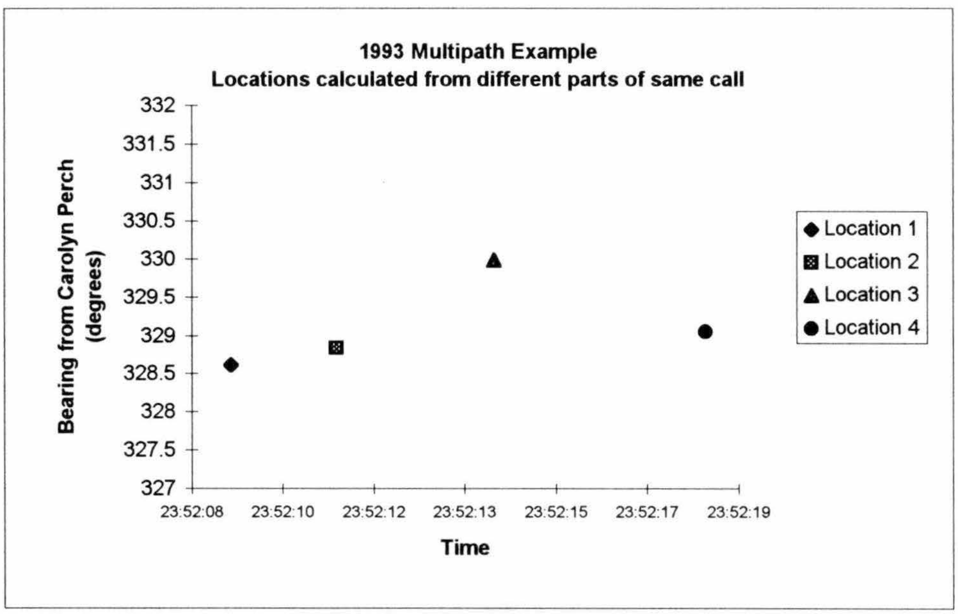

Figure 22. Bearings of the four locations of the descending trill from Carolyn Perch on the 27th of May. Time is AST.

CHAPTER 7: SUMMARY

The bearded seal is a pagophilic arctic seal species mostly associated with pack ice and lead systems (Burns 1981). The type of habitat in which this animal lives restricts the use of routine methods of population and behavioral biology. Acoustic research is fast becoming a tool which may enhance current techniques of research. This study demonstrated the ability to acquire information on the behavior of the bearded seal through the use of bioacoustics.

Using acoustic methods, I found calculated swim speeds for bearded seals to be comparable to values from previous studies. More than 55% of daily bearded seal swim velocities were at slower speeds, 0 - 1 m/s, which may suggest foraging or displaying behaviors. The 9-16% "cruising" velocities may suggest territory or female defense behaviors. The bearing, or directional movement, behavior of these animals suggests that the majority of the seals preferred to swim at angles from the currents. Swim speeds in this study suggest that displaying and territorial defense may require a great deal of energy for a short period of time. Swim speeds also suggest that, while foraging may require less energy for a short period of time, this activity may predominate others and require large amounts of energy overall. Swim speeds and bearings indicate that the seals are maintaining Minimum Cost of Transport (MCT) values and conserving energy.

I analyzed seal movement, distribution, type of movements and abundance to provide information on the behavior of the bearded seal during breeding season. Bearded seals prefer lead systems and leeward sides of ice floes. The acoustic location x-y plots from this study suggest some areas of heavier seal use than others. The satellite image, from the 8th of May 1993, indicated areas of lead systems which correlated with the distribution of seals on the 5th of May 1993. This suggests that seal distribution and spacing are not random, but directly affected by ice conditions. Seal spacing will alter as ice conditions change. Ice conditions as well as atmospheric conditions will also affect the distribution of females on ice flows when they pup. This will, in turn, affect male seal spacing. Furthermore, seasonal changes will alter the consistency and availability of ice floes to females. Also, as pupping ends in mid-May (Burns, 1981), more females will be available to males. All these factors can influence male breeding behavior. Therefore, the seals may adapt their breeding to a combination of vocal display and territorial defense, leaning more towards vocal display when more ice is available and more females are pupping, and then towards territorial defense when more females are available and ice conditions lessen the number of ice floes. The example of movement on the 28th of May suggests that four males displayed in an area. There may have been a female present.

This study was meant to show the importance and the continued usefulness of two dimensional acoustic analysis in behavioral research. Suggestions for future research include the study of multipath error and the effects it has on acoustic data. If a correction value can be obtained, the accuracy of calculated locations will improve. This will in turn offer better information for the study of movements and associations between vocalizing seals.

A second important improvement will be the advances in satellite imaging technology. Enhanced images and programs that are better able to classify ice, as well as open water, will provide much needed visual information. Also, new satellite programs, currently being developed, will allow the researcher to see the temporal growth, disintegration, and distribution change of leads and ice floes. Correlations between acoustic and satellite data will provide distribution and spacing information. It may also provide information on likely areas of female and pup locations on ice floes.

Finally, developing technology may soon allow for the acoustic tagging of seals. By this, I refer to bioacoustic identification of individuals based on individual vocal characteristics. Studying individuals in this fashion will provide a greater understanding of the behavior of this wonderfully vocal seal.

Bibliography

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Appendix 1. 1993 Surface water current data

Table 3. Surface Current Data 1993

Month	Day	Hour	Min	Bearing (Degree) True N	Bearing (Degree) Mag. N	Velocity (m/s)
4	16	8	48	228	203	0.00
4	16	10	34	204	179	0.05
4	16	13	32	204	179	0.11
4	16	16	38	203	178	0.05
4	16	16	55	209	184	0.05
4	23	8	29	246	221	0.28
4	23	17	48	240	215	0.00
4	23	17	49	216	191	0.05
4	23	21	32	217	192	0.08
4	24	5	8	198	173	0.14
4	24	7	3	222	197	0.17
4	24	8	51	203	178	0.33
4	24	10	22	191	166	0.30
4	24	10	41	193	168	0.33
5	5	1	1	233	208	0.53
5	5	5	34	225	200	0.39
5	5	7	42	229	204	0.39
5	5	11	36	214	189	0.33
5	5	13	11	211	186	0.42
5	5	17	57	202	177	0.53
5	5	18	39	229	204	0.42
5	5	21	13	216	191	1.14
5	15	2	28	231	206	0.36
5	15	7	32	230	205	0.25
5	15	13	1	233	208	0.33
5	15	17	32	218	193	0.30
5	15	21	21	217	192	0.30
5	16	1	38	224	199	0.25
5	16	2	42	240	215	0.19

Table 3. cont. Surface Current Data 1993

Month	Day	Hour	Min	Bearing (Degree) True N	Mag. N	Velocity (m/s)
5	16	5	47	231	206	0.25
5	28	2	0	33	8	1.00
5	28	2	45	31	6	1.00
5	28	6	18	63	38	0.47
5	28	9	8	27	2	0.44
5	28	10	18	37	12	0.89
5	28	10	23	32	7	0.86
5	28	13	55	28	3	0.58
5	28	17	29	29	4	0.89
5	28	17	29	31	6	0.83
5	28	19	7	29	4	0.86

Note that two bearings are given, the first is True North and the second is Magnetic North which is 25° less due to the declination angle at Barrow, Alaska. Magnetic north figures were used in the analysis of seal bearings and movements.

Appendix 2. Movement data for seal associations

An example of how to use the data provided to look at seal associations.

Day:	28 May 1993.
Activity seen:	Seal #190 increased speed when in association with Seal #169 and Seal #182.
First:	Go to page 110.
Second:	Find Seal Track #190. It is the first data set.
Third:	Find the Time column and look for 23:22:29. It is in the last row for seal #190.
Fourth:	Follow this row till you intersect with the last column entry 3.05. This is the swim speed at time 23:22:29 for Seal #190.
Fifth:	Find Time 23:18:01 - 23:26:59 for Seal Track #182.
Sixth:	Find Time 23:24:30 for Seal Track #169.
Last:	Seal #190 was in association with Seal #169 and Seal #182. They were all within at least 2 km of one another and vocalized during this time. Also Seal #190 increased its speed to 3.05 m/s at during this association.

23 April 1993 Seal Track #7

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
42306013	11:01:39	C42306013	-2544.09	4983.8	5595.59	332.96		
42306015	11:07:35	C42306015	-2959.72	5540.9	6281.84	331.89	323.27	1.95
42306017	11:13:56	C42306017	-2688.1	5161.87	5819.87	332.49	144.37	1.22
42306019	11:19:41	C42306019	-2689.3	5104.69	5769.77	332.22	181.20	0.17
42306020	11:23:29	C42306020	-2912.43	5312.54	6058.49	331.27	312.97	1.34
42306022	11:30:37	C42306022	-2710.29	5070.48	5749.39	331.87	140.14	0.74
42306027	11:36:08	C42306027	-2904.26	5265.83	6013.63	331.12	315.20	0.83
42306028	11:36:26	C42306028	-2696.85	5057.83	5731.9	331.93	135.08	16.32
42306029	11:39:20	C42306029	-2796.61	5146.67	5857.41	331.48	311.69	0.77
42306030	11:43:57	C42306030	-2844.23	5196.44	5923.9	331.31	316.26	0.25
42306034	11:46:48	C42306034	-2885.3	5162.54	5914.11	330.80	230.46	0.31
42306037	11:53:06	C42306037	-2726.05	4978.66	5676.13	331.30	139.11	0.64
42306039	11:55:41	C42306039	-2854.93	5087.65	5833.93	330.70	310.22	1.09
42306042	12:04:33	C42306042	-2763	4980.49	5695.56	330.98	139.37	0.27
42306043	12:07:23	C42306043	-2805.57	4995.21	5729.17	330.68	289.07	0.26
42306044	12:09:13	C42306044	-2812.11	4993.32	5730.73	330.61	253.88	0.06
42306045	12:10:19	C42306045	-2730.45	4930.06	5635.68	331.02	127.76	1.57
42306047	12:12:48	C42306047	-2938.89	5092.5	5879.68	330.01	307.93	1.77
42306053	12:23:15	C42306053	-2834.93	4980.61	5730.91	330.35	137.10	0.24
42306056	12:26:47	C42306056	-2887.78	4991.46	5766.62	329.95	281.60	0.25
42307002	12:41:21	C42307002	-2947.93	4903.94	5721.79	328.99	214.50	0.12
42307007	12:44:17	C42307007	-2914.19	4834.58	5644.97	328.92	154.06	0.44
42307008	12:44:36	C42307008	-2958.22	4912.41	5734.36	328.94	330.50	4.71
42307009	12:45:14	C42307009	-1414.86	3557.88	3828.88	338.31	131.27	54.04
42307010	12:48:13	C42307010	-2827.67	4758.9	5535.59	329.28	310.37	10.36
42308008	14:51:55	C42308008	-3112.66	4528.12	5494.78	325.50	231.00	0.05
42308009	14:52:30	C42308009	-2654.98	4156.26	4931.88	327.43	129.09	16.85
42308011	14:54:33	C42308011	-2704.34	4189.54	4986.55	327.16	303.99	0.48
42308013	14:56:08	C42308013	-2372.5	3879.6	4547.53	328.55	133.05	4.78
42308016	14:59:08	C42308016	-2737.64	4074.56	4908.84	326.10	298.10	2.30
42308017	14:59:35	C42308017	-2259.52	3890.68	4499.2	329.85	111.04	18.97
42308019	15:01:39	C42308019	-2767.07	4101.2	4947.37	325.99	292.53	4.43
42308020	15:03:44	C42308020	-2555.76	3823.08	4598.67	326.24	142.77	2.79
42308021	15:04:22	C42308021	-2687.68	3984.79	4806.48	326.00	320.79	5.49
42308023	15:09:02	C42308023	-2918.78	4035.36	4980.3	324.12	282.34	0.84
42308024	15:10:35	C42308024	-2757.46	3920.05	4792.75	324.88	125.56	2.13
42308025	15:12:57	C42308025	-2896.64	3996.52	4935.86	324.07	298.79	1.12
42308026	15:14:58	C42308026	-2675.65	3785.63	4635.74	324.75	133.66	2.52
42308028	15:18:07	C42308028	-2834.86	3820.69	4757.54	323.43	282.42	0.86
42308029	15:20:03	C42308029	-3206.91	4116.61	5218.31	322.08	308.50	4.10
42308030	15:23:51	C42308030	-2954.55	3888.21	4883.39	322.77	132.15	1.49
42308031	15:25:50	C42308031	-3185.38	3998.7	5112.36	321.46	295.58	2.15
42308032	15:26:23	C42308032	-3266.79	4067.68	5217.08	321.23	310.28	3.23
42308033	15:26:57	C42308033	-2893.01	3791.43	4769.11	322.66	126.47	13.67
42308034	15:29:29	C42308034	-3079.9	3807.85	4897.5	321.03	275.02	1.23
42308036	15:31:26	C42308036	-3153.25	3900.47	5015.64	321.05	321.62	1.01
42308037	15:34:26	C42308037	-2947.39	3686.13	4719.6	321.36	136.16	1.65
42308038	15:36:33	C42308038	-3214.6	3822.67	4994.64	319.94	297.07	2.36
42308041	15:38:57	C42308041	-3199.43	3797.54	4965.65	319.89	148.88	0.20
42308043	15:40:37	C42308043	-3316.99	3820.45	5059.47	319.04	281.03	1.20
42308059	16:07:11	C42308059	-3109.47	3560.08	4726.84	318.87	141.44	0.21
42308060	16:09:48	C42308060	-3115.24	3508.96	4692.28	318.40	186.44	0.33
42308063	16:12:02	C42308063	-2920.37	3434.99	4508.62	319.63	110.79	1.56
42308067	16:17:53	C42308067	-3180.06	3392.47	4649.91	316.85	260.70	0.75
42308070	16:19:46	C42308070	-3313.16	3412.32	4756.15	315.85	278.48	1.19
42308071	16:20:46	C42308071	-3277.33	3388.32	4713.97	315.95	123.82	0.72
42308072	16:22:56	C42308072	-3333.19	3373.49	4742.42	315.34	255.13	0.44
42308074	16:25:23	C42308074	-3466.77	3389.77	4848.62	314.36	276.95	0.92
42308075	16:27:55	C42308075	-3455.85	3311.12	4786.06	313.78	172.10	0.52
42308076	16:31:20	C42308076	-3499.51	3298.99	4809.36	313.31	254.47	0.22
42308077	16:32:13	C42308077	-3398.42	3258.54	4708.22	313.80	111.81	2.05
42309023	16:57:38	C42309023	-2336.34	3751.04	4419.14	328.08	65.12	0.77

23 April 1993 Seal Track #7 cont.

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
42309028	17:07:49	C42309028	-2445.34	3833.36	4546.9	327.47	307.06	0.22
42309029	17:08:24	C42309029	-2595.4	3957.74	4732.84	326.74	309.65	5.57
42309031	17:13:45	C42309031	-2633.24	3856.32	4669.6	325.67	200.46	0.34
42309032	17:14:53	C42309032	-2974.12	4086.07	5053.85	323.95	303.98	6.05
42309033	17:16:55	C42309033	-2708.94	3839.87	4699.25	324.80	132.87	2.97
42309034	17:17:38	C42309034	-1910.6	3397.24	3897.65	330.65	119.01	21.23
42309039	17:20:55	C42309039	-2855.43	3916.39	4846.82	323.90	298.79	5.47
42309040	17:23:17	C42309040	-2937.48	3872.24	4860.35	322.82	241.72	0.66
42309041	17:27:18	C42309041	-2759.12	3644.43	4571.06	322.87	141.94	1.20
42309042	17:30:46	C42309042	-2913.01	3676.24	4690.45	321.61	281.68	0.76
42309063	18:25:24	C42309063	-2453.49	3472.66	4251.94	324.76	113.89	0.15
42309065	18:28:02	C42309065	-2435.44	3399.12	4181.56	324.38	166.21	0.48
42309066	18:29:56	C42309066	-2367	3274.97	4040.81	324.14	151.13	1.24
42309068	18:31:37	C42309068	-2523.54	3388.8	4225.19	323.33	306.02	1.92
42309069	18:34:19	C42309069	-2527.15	3302.01	4158.1	322.57	182.38	0.54
42309070	18:36:33	C42309070	-2437.31	3205.5	4026.87	322.75	137.05	0.98
42310006	18:48:54	C42310006	-2537.44	3049.81	3967.36	320.24	212.75	0.25
42310016	19:02:23	C42310016	-2269.85	2801.61	3605.72	320.99	132.85	0.45
42310021	19:09:41	C42310021	-2365	2803.56	3667.86	319.85	271.17	0.22
42310032	19:30:11	C42310032	-2697.6	3022.07	4050.92	318.25	303.30	0.32
42310033	19:31:04	C42310033	-2490.52	2877.24	3805.41	319.12	124.97	4.77
42310035	19:35:26	C42310035	-2783.48	2980.74	4078.3	316.96	289.46	1.19
42310037	19:36:11	C42310037	-2753.29	2932.08	4022.15	316.80	148.18	1.27
42310038	19:36:39	C42310038	-2745.84	2921.98	4009.69	316.78	143.59	0.45
42310039	19:37:47	C42310039	-2758.04	2874.18	3983.43	316.18	194.32	0.73
42310040	19:39:08	C42310040	-2784.4	2898.92	4019.54	316.15	313.18	0.45
42310042	19:41:10	C42310042	-3000.42	2938.74	4199.85	314.41	280.44	1.80
42310053	19:57:48	C42310053	-2069.52	2889.11	3553.86	324.39	93.05	0.93
42310054	19:58:06	C42310054	-2240.16	3046.94	3781.81	323.68	312.77	12.91
42310058	20:01:32	C42310058	-2873.85	3130.24	4249.4	317.45	277.49	3.10
42310060	20:02:25	C42310060	-2769.36	3101.62	4158.05	318.24	105.32	2.04
42310066	20:12:34	C42310066	-2444.76	3053.11	3911.31	321.31	98.50	0.54
42310068	20:13:20	C42310068	-2443.4	3004.28	3872.45	320.88	178.40	1.06
42310070	20:16:28	C42310070	-2446.96	2961.39	3841.54	320.43	184.74	0.23
42310072	20:19:09	C42310072	-2251.53	2756.84	3559.43	320.76	136.31	1.76
42311002	20:41:26	C42311002	-2694.33	3359.17	4306.21	321.27	323.68	0.56
42311003	20:42:14	C42311003	-2670.71	3337.2	4274.3	321.33	132.93	0.67
42311005	20:42:38	C42311005	-2378.33	3257.95	4033.7	323.87	105.17	12.62
42311007	20:44:26	C42311007	-2581.27	3191.33	4104.57	321.03	251.83	1.98
42311011	20:46:25	C42311011	-2540.57	3137.98	4037.5	321.01	142.66	0.56
42311013	20:47:52	C42311013	-2443.6	3023.82	3887.76	321.06	139.65	1.72
42311014	20:49:07	C42311014	-2636.34	3197.01	4143.81	320.49	311.94	3.45
42311017	20:50:26	C42311017	-2803.9	3261.91	4301.39	319.32	291.17	2.27
42311023	20:53:08	C42311023	-2627.37	3127.81	4084.88	319.97	127.22	1.37
42311026	20:54:52	C42311026	-2771.62	3148.52	4194.64	318.64	278.17	1.40
42311027	20:56:38	C42311027	-3044.47	3334.47	4515.25	317.60	304.27	3.11
42311029	20:58:47	C42311029	-3148.51	3229.97	4510.63	315.73	224.87	1.14
42311031	21:01:19	C42311031	-3029.3	3111.93	4342.89	315.77	134.72	1.10
42311033	21:01:59	C42311033	-2854.2	3052.91	4179.32	316.93	108.63	4.62
42311035	21:03:05	C42311035	-2975.59	3064.31	4271.31	315.84	275.37	1.85
42311037	21:04:01	C42311037	-2919.61	3021.87	4201.89	315.99	127.17	1.25
42311038	21:04:30	C42311038	-3148.82	3081.75	4405.93	314.38	284.64	8.17
42311040	21:06:41	C42311040	-2863.97	2964.89	4122.24	315.99	112.31	2.35
42311042	21:07:53	C42311042	-3027.92	2976.1	4245.64	314.51	273.91	2.28
42311043	21:09:09	C42311043	-3052.6	2944.96	4241.59	313.97	218.40	0.52
42311046	21:10:29	C42311046	-3016.83	2899.95	4184.61	313.87	141.53	0.72
42311048	21:11:48	C42311048	-2805.33	2723.5	3909.9	314.15	129.84	3.49
42311049	21:13:18	C42311049	-3111.63	2839.3	4212.34	312.38	290.71	3.64
42311050	21:14:03	C42311050	-3068.59	2848.6	4186.98	312.87	77.81	0.98
42311052	21:14:55	C42311052	-3332.52	2881.7	4405.67	310.85	277.15	5.12
42311053	21:17:12	C42311053	-3113.36	2790.32	4180.77	311.87	112.63	1.73
42311054	21:17:44	C42311054	-3255.95	2850.29	4327.28	311.20	292.81	4.83

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LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
42311055	21:18:58	C42311055	-3103.19	2751.57	4147.4	311.56	122.87	2.46
42311057	21:19:03	C42311057	-3162.84	2785.26	4214.4	311.37	299.46	13.70
42311058	21:19:13	C42311058	-3005.95	2681.06	4027.88	311.73	123.59	18.83
42311059	21:19:28	C42311059	-3147.44	2768.22	4191.59	311.33	301.63	11.08
42311064	21:24:15	C42311064	-3202.53	2704.36	4191.63	310.18	220.78	0.29
42311066	21:26:00	C42311066	-3250.05	2645.1	4190.39	309.14	218.73	0.72
42311067	21:28:02	C42311067	-3354.98	2614.36	4253.32	307.93	253.67	0.90
42311069	21:29:59	C42311069	-3292.66	2561.38	4171.61	307.88	130.37	0.70
42311070	21:30:18	C42311070	-3208.8	2543.38	4094.53	308.40	102.11	4.51
42311071	21:30:52	C42311071	-3314.37	2580.03	4200.19	307.90	289.15	3.29
42311075	21:33:02	C42311075	-3261.27	2491.75	4104.23	307.38	148.97	0.79
42311077	21:34:12	C42311077	-3361.22	2471.68	4172.17	306.33	258.65	1.46
42311078	21:35:09	C42311078	-3554.3	2510.71	4351.63	305.24	281.43	3.46
42311079	21:36:24	C42311079	-3460.82	2458.11	4244.95	305.39	119.37	1.43
42311080	21:37:01	C42311080	-3547.52	2462.57	4318.46	304.77	272.94	2.35
42311081	21:37:15	C42311081	-3730.09	2501.46	4491.2	303.85	282.03	13.33
42311083	21:39:20	C42311083	-3420.76	2390.17	4173.07	304.94	109.79	2.63
42311085	21:42:03	C42311085	-3580.54	2377.14	4297.8	303.58	265.34	0.98
42311086	21:43:18	C42311086	-3568.27	2338.7	4266.39	303.24	162.30	0.54
42311090	21:46:13	C42311090	-3577.4	2289.82	4247.48	302.62	190.58	0.28
42311093	21:49:18	C42311093	-3593.53	2230.52	4229.5	301.83	195.22	0.33
42311095	21:51:33	C42311095	-3662.99	2181.6	4263.43	300.78	234.84	0.63
42311098	21:52:51	C42311098	-3709.32	2161.05	4292.92	300.23	246.08	0.65
42311099	21:53:28	C42311099	-3602.96	2127.17	4184.03	300.56	107.67	3.02
42311101	21:58:26	C42311101	-3587	1997.95	4105.9	299.12	172.96	0.44
42311103	22:00:51	C42311103	-3738.73	2004.53	4242.2	298.20	272.48	1.05
42311104	22:03:01	C42311104	-3828.5	1936.56	4290.42	296.83	232.87	0.87
42311106	22:06:22	C42311106	-3809.88	1893.24	4254.35	296.42	156.74	0.23
42311109	22:08:02	C42311109	-3652.55	1801.64	4072.72	296.26	120.21	1.82
42311110	22:09:33	C42311110	-3864.78	1831.46	4276.77	295.36	278.00	2.36
42311115	22:12:14	C42311115	-3917.3	1806.15	4313.63	294.75	244.27	0.36
42311118	22:15:02	C42311118	-4066.31	1748.25	4426.21	293.27	248.77	0.95
42311119	22:15:55	C42311119	-4049.68	1765.67	4417.86	293.56	43.67	0.45
42311121	22:16:52	C42311121	-3897.48	1737.75	4267.33	294.03	100.39	2.71
42311122	22:20:07	C42311122	-3940.92	1642.25	4269.41	292.62	204.46	0.54
42311123	22:21:40	C42311123	-4123.34	1662.46	4445.86	291.96	276.32	1.97
42311125	22:24:06	C42311125	-4153.62	1629.37	4461.77	291.42	222.46	0.31
42311126	22:26:32	C42311126	-4011.3	1606.1	4320.89	291.82	99.29	0.99
42311128	22:28:13	C42311128	-4106.09	1519.44	4378.2	290.31	227.57	1.27
42311130	22:29:35	C42311130	-4373.83	1498.86	4623.53	288.92	265.60	3.27
42311131	22:30:57	C42311131	-4268.01	1430.73	4501.44	288.53	122.77	1.53
42311132	22:32:39	C42311132	-4141.58	1432.42	4382.3	289.08	89.23	1.24
42311133	22:33:26	C42311133	-4146	1432.6	4386.53	289.06	272.33	0.09
42311134	22:34:46	C42311134	-4240.74	1391.8	4463.29	288.17	246.70	1.29
42311135	22:35:52	C42311135	-4429.58	1347.04	4629.87	286.92	256.67	2.94
42311138	22:37:32	C42311138	-4131.2	1333.8	4341.18	287.89	92.54	2.99
42311141	22:40:14	C42311141	-4195.67	1292.99	4390.39	287.13	237.67	0.47
42312001	22:42:00	C42312001	-4262.71	1249.53	4442.08	286.34	237.05	0.75
42312006	22:45:01	C42312006	-4046.88	1221.45	4227.19	286.80	97.41	1.20
42312010	22:46:56	C42312010	-4084.66	1127.62	4237.45	285.43	201.93	0.88
42312011	22:47:48	C42312011	-4363.21	1084.08	4495.87	283.95	261.12	5.42
42312012	22:49:25	C42312012	-4073.44	1062.24	4209.66	284.62	94.31	3.00
42312014	22:50:51	C42312014	-4128.79	1042.15	4258.29	284.17	250.05	0.68
42312015	22:51:50	C42312015	-4149.22	1005.55	4269.33	283.62	209.17	0.71
42312016	22:51:57	C42312016	-4241.17	1025.83	4363.47	283.60	282.44	13.45
42312018	22:53:15	C42312018	-3572.22	892.273	3681.97	284.02	101.29	8.75
42312019	22:54:16	C42312019	-4073.41	931.104	4178.47	282.88	274.43	8.24
42312021	22:56:28	C42312021	-3841.1	852.4	3934.54	282.51	108.72	1.86
42312022	22:56:52	C42312022	-4476.91	799.065	4547.66	280.12	265.20	26.59
42312025	23:00:08	C42312025	-4093.19	867.58	4184.12	281.97	79.88	1.99
42312026	23:00:35	C42312026	-4125.36	860.845	4214.22	281.79	258.18	1.22
42312028	23:02:39	C42312028	-4347.15	877.913	4434.91	281.42	274.40	1.79

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LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
42312029	23:03:03	C42312029	-4216.23	842.377	4299.55	281.30	105.19	5.65
42312030	23:03:39	C42312030	-4410.12	815.876	4484.96	280.48	262.22	5.44
42312031	23:05:06	C42312031	-4225.31	797.229	4299.87	280.69	95.76	2.14
42312033	23:06:58	C42312033	-4150.33	762.44	4219.78	280.41	114.89	0.74
42312034	23:07:54	C42312034	-4367.74	729.028	4428.16	279.48	261.26	3.93
42312036	23:09:54	C42312036	-4072.69	704.188	4133.12	279.81	94.81	2.47
42312040	23:11:43	C42312040	-4439.23	567.136	4475.31	277.28	249.50	3.59
42312045	23:17:48	C42312045	-4234.21	483.164	4261.69	276.51	112.27	0.61
42312046	23:18:01	C42312046	-4253.38	450.556	4277.18	276.05	210.45	2.91
42312047	23:19:19	C42312047	-4099.21	406.968	4119.36	275.67	105.79	2.05
42312048	23:20:02	C42312048	-4503.2	392.217	4520.25	274.98	267.91	9.40
42312050	23:22:57	C42312050	-4286.32	388.888	4303.93	275.18	90.88	1.24
42312053	23:24:55	C42312053	-4648.22	253.384	4655.13	273.12	249.47	3.27
42312054	23:25:28	C42312054	-4456.39	191.747	4460.51	272.46	107.81	6.11
42312055	23:27:05	C42312055	-4116.05	296.905	4126.74	274.13	72.83	3.67
42312056	23:28:06	C42312056	-4188.83	258.443	4196.79	273.53	242.14	1.35
42312058	23:29:51	C42312058	-4242.96	220.156	4248.67	272.97	234.73	0.63
42312059	23:31:33	C42312059	-4457.3	168.677	4460.49	272.17	256.49	2.16
42312060	23:32:12	C42312060	-4166.78	172.071	4170.33	272.37	89.33	7.45
42312061	23:34:58	C42312061	-4428.62	59.007	4429.02	270.76	246.65	1.72
42312062	23:36:42	C42312062	-4435.52	43.3	4435.73	270.56	203.72	0.16
42312064	23:37:07	C42312064	-4227.12	57.707	4227.51	270.78	86.05	8.36
42312065	23:38:15	C42312065	-4600.17	-93.8603	4601.13	268.83	247.89	5.92
42312066	23:40:03	C42312066	-4802.36	-317.834	4812.87	266.21	222.07	2.79
42312067	23:45:21	C42312067	-4613.04	-274.595	4621.21	266.59	77.13	0.61
42312069	23:47:39	C42312069	-4599.07	-219.159	4604.29	267.27	14.14	0.41
42312071	23:50:39	C42312071	-4557.8	-205.554	4562.43	267.42	71.75	0.24
42312073	23:55:46	C42312073	-4391.58	-338.223	4404.59	265.60	128.60	0.69
42312074	23:56:17	C42312074	-3969.43	-194.534	3974.19	267.19	71.20	14.38
42312075	23:58:50	C42312075	-3812.33	-225.789	3819.01	266.61	101.25	1.05
42412077	0:00:55	C42400077	-4354.67	-414.339	4374.33	264.57	250.83	4.59
42412078	0:01:20	C42400078	-4276.94	-353.174	4291.5	265.28	51.80	3.96
42412079	0:04:01	C42400079	-4481.23	-550.052	4514.87	263.00	226.06	1.76
42412081	0:05:25	C42400081	-4593.89	-606.132	4633.7	262.48	243.54	1.50
42412082	0:07:57	C42400082	-4341.65	-587.772	4381.26	262.29	85.84	1.66
42412084	0:10:05	C42400084	-4492.44	-666.793	4541.65	261.56	242.34	1.33
42412085	0:12:54	C42400085	-4445.93	-717.37	4503.43	260.83	137.40	0.41
42412087	0:14:14	C42400087	-4356.2	-707.395	4413.26	260.78	83.66	1.13
42412088	0:14:45	C42400088	-4349.35	-709.784	4406.88	260.73	109.23	0.23
42412091	0:17:03	C42400091	-4405.64	-768.243	4472.12	260.11	223.92	0.59
42412093	0:21:35	C42400093	-4375.22	-875.781	4462.01	258.68	164.21	0.41
42412095	0:22:26	C42400095	-4414.68	-900.162	4505.51	258.48	238.29	0.91
42412097	0:23:41	C42400097	-4398.24	-897.414	4488.86	258.47	80.51	0.22
42412098	0:25:12	C42400098	-4329.28	-888.618	4419.54	258.40	82.73	0.76
42412100	0:26:45	C42400100	-4398.19	-968.553	4503.57	257.58	220.76	1.13
42412102	0:28:47	C42400102	-4216.83	-928.457	4317.84	257.58	77.53	1.52
42412103	0:32:00	C42400103	-4266.61	-1004.02	4383.15	256.76	213.38	0.47
42412104	0:33:18	C42400104	-4460.34	-1095.22	4592.84	256.20	244.79	2.75
42412107	0:36:12	C42400107	-4355.73	-1089.88	4490.02	255.95	87.08	0.60
42412109	0:40:09	C42400109	-4399.54	-1186.4	4556.7	254.91	204.41	0.45
42412111	0:40:51	C42400111	-4403.4	-1201.19	4564.29	254.74	194.63	0.36
42412113	0:42:18	C42400113	-4359	-1218.83	4526.19	254.38	111.67	0.55
42401001	0:45:14	C42401001	-4760.67	-1462.76	4980.33	252.92	238.73	2.67
42401003	0:48:26	C42401003	-4498.19	-1419.71	4716.92	252.48	80.69	1.39
42401006	0:51:40	C42401006	-4396.25	-1414.91	4618.33	252.16	87.30	0.53
42401010	0:53:37	C42401010	-4339.9	-1455.1	4577.34	251.47	125.50	0.59
42401012	0:58:12	C42401012	-4362.91	-1588.9	4643.23	249.99	189.76	0.49
42401014	0:59:57	C42401014	-4399.91	-1662.6	4703.55	249.30	206.66	0.79
42401015	1:00:06	C42401015	-4322.33	-1623.92	4617.32	249.41	63.50	9.63
42401016	1:02:01	C42401016	-4330.68	-1701.66	4653	248.55	186.13	0.68
42401017	1:03:45	C42401017	-4326.6	-1714.95	4654.08	248.38	162.93	0.13
42401020	1:07:33	C42401020	-4561.29	-1890.08	4937.39	247.49	233.27	1.28

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LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
42401021	1:09:26	C42401021	-4365.15	-1824.44	4731.08	247.32	71.50	1.83
42401022	1:15:29	C42401022	-4624.35	-2154.04	5101.42	245.02	218.18	1.16
42401023	1:16:51	C42401023	-4390.97	-1979.05	4816.36	245.74	53.14	3.56
42401024	1:17:00	C42401024	-4410.79	-2025.45	4853.61	245.34	203.13	5.61
42401025	1:17:32	C42401025	-4691.07	-2267.46	5210.33	244.20	229.19	11.57
42401029	1:23:20	C42401029	-4279.21	-2068.66	4753	244.20	64.23	1.31
42401030	1:23:56	C42401030	-4430.27	-2186.41	4940.41	243.73	232.06	5.32
42401031	1:25:07	C42401031	-4239.05	-2080.07	4721.89	243.86	60.92	3.08
42401035	1:28:09	C42401035	-4022.23	-1948.77	4469.45	244.15	58.80	1.39
42401036	1:30:03	C42401036	-3852.47	-2113.12	4393.95	241.26	134.07	2.07
42401037	1:30:48	C42401037	-4535.01	-2401.46	5131.6	242.10	247.10	16.47
42401039	1:34:56	C42401039	-4240.71	-2251.64	4801.41	242.03	63.02	1.33
42401041	1:36:21	C42401041	-4386.1	-2439.08	5018.66	240.92	217.80	2.79
42401043	1:38:14	C42401043	-4350.9	-2407.87	4972.74	241.04	48.44	0.42
42401044	1:40:27	C42401044	-4527.19	-2628.15	5234.75	239.86	218.67	2.12
42401045	1:42:09	C42401045	-4231.15	-2444.56	4886.56	239.98	58.19	3.42
42401049	1:45:08	C42401049	-4602.21	-2839.13	5407.5	238.33	223.24	3.03
42401054	1:51:27	C42401054	-4509.14	-2828.67	5322.94	237.90	83.59	0.25
42401056	1:55:38	C42401056	-4335.23	-2715.6	5115.54	237.94	56.97	0.83
42401059	1:58:41	C42401059	-4324.84	-2801.98	5153.19	237.06	173.14	0.48
42401062	2:00:41	C42401062	-4170.59	-2651.64	4942.16	237.55	45.74	1.79
42401063	2:01:07	C42401063	-4366.62	-2869.45	5225.05	236.69	221.99	11.27
42401064	2:04:58	C42401064	-4639.48	-3091.74	5575.27	236.32	230.83	1.52
42401066	2:09:04	C42401066	-4256.69	-3044.26	5233.25	234.43	82.93	1.57
42401069	2:13:08	C42401069	-4310.58	-3103.8	5311.75	234.24	222.15	0.33
42401071	2:17:19	C42401071	-4310.97	-3212.65	5376.39	233.31	180.21	0.43
42401072	2:17:59	C42401072	-4168.79	-3080.37	5183.38	233.54	47.07	4.85
42401073	2:20:28	C42401073	-4161.58	-3140.37	5213.51	232.96	173.15	0.41
42401075	2:23:34	C42401075	-4547.05	-3302.84	5620	234.01	247.15	2.25
42401077	2:24:57	C42401077	-4304.41	-3352.7	5456.06	232.09	101.61	2.98
42401084	2:34:55	C42401084	-4277.74	-3328.28	5420.01	232.12	47.52	0.06
42401085	2:36:33	C42401085	-4317.99	-3540.2	5583.73	230.65	190.75	2.20
42401086	2:39:19	C42401086	-3950.97	-3112.84	5029.9	231.77	40.66	3.39
42401089	2:41:41	C42401089	-3595.71	-3076.59	4732.29	229.45	84.17	2.51
42402004	2:50:55	C42402004	-3919.66	-3379.08	5175.13	229.24	226.96	0.80
42402019	3:01:49	C42402019	-4225.92	-3968.44	5797.15	226.80	207.46	1.02
42402021	3:05:58	C42402021	-4151.9	-3978.69	5750.5	226.22	97.88	0.30
42402023	3:06:28	C42402023	-4196.26	-4028.42	5816.94	226.17	221.73	2.22
42402030	3:10:27	C42402030	-4037.21	-3985.19	5672.81	225.37	74.79	0.69
42402034	3:13:44	C42402034	-4393.87	-4345.46	6179.73	225.32	224.71	2.57
42402037	3:17:46	C42402037	-4105.29	-4162.55	5846.38	224.60	57.63	1.41
42402041	3:23:58	C42402041	-3863.39	-4106.24	5637.99	223.26	76.90	0.67
42402043	3:24:14	C42402043	-3953.74	-4209.77	5775.31	223.20	221.11	8.59
42402054	3:33:07	C42402054	-3803.14	-4178.66	5650.23	222.31	78.33	0.29

23 April 1993 Seal Track #12

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
42306036	11:50:25	C42306036	-2253.47	4212.4	4777.28	331.86		
42306054	12:23:32	C42306054	-2345.37	4194.69	4805.85	330.79	259.09	0.05

23 April 1993 Seal Track #1

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
42306001	10:35:26	C42306001	-2389.43	2571.87	3510.54	317.11		
42306002	10:38:50	C42306002	-2505.46	2607.33	3616.01	316.14	286.99	0.59
42306003	10:43:43	C42306003	-2470.38	2594.17	3582.25	316.40	110.56	0.13
42306004	10:46:16	C42306004	-2427.13	2591.84	3550.86	316.88	93.08	0.28
42306005	10:47:28	C42306005	-2437.92	2596.17	3561.4	316.80	291.87	0.16
42306009	10:50:19	C42306009	-2587.63	2659.09	3710.33	315.78	292.80	0.95
42306010	10:50:35	C42306010	-2494.18	2623.9	3620.19	316.45	110.63	6.24

23 April 1993 Seal Track #1 cont.

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
42307033	14:04:04	C42307033	-2451.84	2327.73	3380.81	313.51	171.86	0.03
42307035	14:05:37	C42307035	-2339.24	2269.38	3259.16	314.13	117.39	1.36
42307036	14:06:54	C42307036	-2520.55	2366.53	3457.4	313.20	298.18	2.67
42307037	14:08:22	C42307037	-2547.81	2380.8	3487.05	313.06	297.63	0.35
42307039	14:11:21	C42307039	-2545.69	2358.48	3470.29	312.81	174.57	0.13
42307041	14:13:37	C42307041	-2508.81	2333.63	3426.36	312.93	123.97	0.33
42307042	14:14:41	C42307042	-2496.15	2316.52	3405.44	312.86	143.50	0.33
42307043	14:16:20	C42307043	-2140.3	2236.46	3095.58	316.26	102.68	3.68
42307045	14:18:49	C42307045	-2556.7	2352.67	3474.44	312.62	285.59	2.90
42307047	14:21:25	C42307047	-2506.99	2314.82	3412.24	312.72	127.29	0.40
42307049	14:23:31	C42307049	-2343.2	2185.07	3203.92	313.00	128.39	1.66
42307050	14:26:18	C42307050	-2305.64	2092.29	3113.46	312.22	157.96	0.60
42307051	14:28:07	C42307051	-2543.73	2230.65	3383.24	311.25	300.16	2.53
42307052	14:33:26	C42307052	-2570.75	2217.52	3395.02	310.78	244.08	0.09
42308001	14:41:02	C42308001	-2484.84	2089.81	3246.81	310.07	146.07	0.34
42308002	14:42:40	C42308002	-2576.63	2142.05	3350.73	309.74	299.65	1.08
42308003	14:44:27	C42308003	-2695.5	2127.84	3434.15	308.29	263.18	1.12
42308004	14:47:05	C42308004	-2621.8	2093.49	3355.07	308.61	114.99	0.51
42308005	14:48:20	C42308005	-2568.3	2057.3	3290.69	308.70	124.08	0.86
42308010	14:53:45	C42308010	-2544.51	1913.34	3183.61	306.94	170.62	0.45
42308015	14:58:09	C42308015	-2628.57	1976.62	3288.83	306.94	306.97	0.40
42308018	15:00:05	C42308018	-2674.56	1962.59	3317.39	306.27	253.03	0.41

23 April 1993 Seal Track #10

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing
42306025	11:34:15	C42306025	-3888.64	6286.77	7392.23	328.26

23 April 1993 Seal Track #46

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
42309002	16:37:00	C42309002	-3579.54	3238.53	4827.13	312.14		
42309006	16:40:02	C42309006	-3570.37	3202.64	4796.3	311.89	165.67	0.20
42309007	16:41:49	C42309007	-3665.72	3205.39	4869.5	311.17	271.65	0.89
42309008	16:42:40	C42309008	-3541.66	3161.24	4747.29	311.75	109.59	2.58
42309010	16:44:39	C42309010	-3455.05	3108.02	4647.27	311.97	121.57	0.85
42309013	16:46:18	C42309013	-3590.76	3100.4	4744.05	310.81	266.79	1.37
42309016	16:47:31	C42309016	-3595.59	3124.53	4763.5	310.99	348.68	0.34
42309017	16:49:05	C42309017	-3569.21	3066.11	4705.34	310.66	155.70	0.68
42309019	16:50:37	C42309019	-3410.29	3009.57	4548.36	311.43	109.58	1.83
42309020	16:52:26	C42309020	-3600.58	3004.53	4689.5	309.84	268.48	1.75

23 April 1993 Seal Track #148

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
42402007	2:52:55	C42402007	-3339.95	-2757.39	4331.1	230.46		
42402008	2:53:30	C42402008	-3665.37	-3027.58	4754.07	230.44	230.30	12.08
42402012	2:56:12	C42402012	-3697.35	-3278.55	4941.58	228.44	187.26	1.56
42402015	2:57:49	C42402015	-3727.52	-3370.99	5025.73	227.88	198.08	1.00
42402020	3:04:12	C42402020	-3783.67	-3558.37	5194.05	226.76	196.68	0.51
42402042	3:24:07	C42402042	-3706.6	-3878.09	5364.56	223.71	166.45	0.28
42402049	3:28:50	C42402049	-3731.7	-4071.03	5522.58	222.51	187.41	0.69
42402057	3:34:13	C42402057	-3555.9	-3936.67	5304.88	222.09	52.61	0.69
42402069	3:42:38	C42402069	-3430.43	-3983.54	5257.03	220.73	110.48	0.27
42402074	3:47:01	C42402074	-3372.53	-4096.89	5306.45	219.46	152.94	0.48
42402077	3:51:45	C42402077	-3351.65	-4099.55	5295.27	219.27	97.26	0.07
42402078	3:53:45	C42402078	-3156.4	-4002	5096.94	218.26	63.45	1.82
42402096	4:14:33	C42402096	-3063.11	-4256.81	5244.34	215.74	159.89	0.22

23 April 1993 Seal Track #118

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing
42412096	0:23:07	C42400096	-4704.92	-2193.34	5191.05	245.01

23 April 1993 Seal Track #153

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing
42402018	3:00:01	C42402018	-3257.75	-2836.79	4319.76	228.95

23 April 1993 Seal Track #162

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
42402039	3:21:17	C42402039	-3998.13	-2790.9	4875.88	235.08		
42402076	3:49:10	C42402076	-3812.98	-2356.75	4482.53	238.28	23.10	0.28
42402104	4:22:28	C42402104	-4314.47	-2872.39	5183.18	236.35	224.20	0.36

23 April 1993 Seal Track #165

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
42402048	3:27:50	C42402048	-6060.67	-4584.49	7599.29	232.90		
42402050	3:28:50	C42402050	-5687.21	-4174.83	7055.04	233.72	42.35	9.24
42402068	3:41:38	C42402068	-6078.32	-4985.31	7861.25	230.64	205.76	1.17
42402101	4:18:37	C42402101	-6376.45	-4528.13	7820.68	234.62	326.89	0.25

28 May 1993 Seal Track #190

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
52811093	22:48:32	C52811093	-7947.13	1070.77	8018.94	277.67		
52811098	22:52:35	C52811098	-8343.51	1089.3	8414.32	277.44	272.68	1.63
52811139	23:18:39	C52811139	-8575.81	1255.02	8667.16	278.33	305.50	0.18
52811147	23:22:29	C52811147	-7880.18	1171.66	7966.81	278.46	96.83	3.05

28 May 1993 Seal Track #169

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
52810091	21:22:28	C52810091	-6905.8	-122.201	6906.88	268.99		
52811021	21:55:46	C52811021	-7183.81	231.695	7187.54	271.85	321.85	0.23
52811031	22:04:58	C52811031	-7306.95	387.501	7317.21	273.04	321.68	0.36
52811041	22:13:56	C52811041	-7420.89	548.151	7441.1	274.23	324.65	0.37
52811061	22:26:16	C52811061	-7644.6	668.832	7673.81	275.00	298.34	0.34
52811063	22:29:50	C52811063	-7153.13	723.263	7189.6	275.77	83.68	2.31
52811075	22:35:08	C52811075	-7355.24	794.92	7398.08	276.17	289.52	0.67
52811087	22:42:38	C52811087	-7673.72	923.909	7729.14	276.87	292.05	0.76
52811089	22:45:02	C52811089	-7435.81	947.486	7495.93	277.26	84.34	1.66
52811096	22:51:42	C52811096	-7156.54	1021.98	7229.14	278.13	75.06	0.72
52811106	22:58:07	C52811106	-7075.6	1070.27	7156.09	278.60	59.18	0.24
52811120	23:08:22	C52811120	-7336.52	1256.43	7443.33	279.72	305.51	0.52
52811150	23:24:30	C52811150	-7016.8	1351.74	7145.82	280.90	73.40	0.34
52811157	23:30:26	C52811157	-6778.88	1382.06	6918.33	281.52	82.74	0.67
52811164	23:36:08	C52811164	-6844.44	1487.64	7004.25	282.26	328.16	0.36
52811167	23:38:17	C52811167	-7085.12	1574.09	7257.87	282.53	289.76	1.98
52812003	23:41:30	C52812003	-7039.74	1641.73	7228.64	283.13	33.86	0.42
52812004	23:41:57	C52812004	-7079.92	1266.93	7192.38	280.15	186.12	13.96
52812008	23:45:09	C52812008	-6382.65	1610.97	6582.82	284.17	63.74	4.05
52812014	23:48:03	C52812014	-6346.07	1615.64	6548.5	284.28	82.72	0.21
52812017	23:51:39	C52812017	-6500.58	1706.8	6720.91	284.71	300.54	0.83
52912036	0:07:57	C52900036	-6450.16	1896.82	6723.28	286.39	14.86	0.20
52912041	0:11:55	C52900041	-6442.11	1941.21	6728.23	286.77	10.28	0.19
52912045	0:15:20	C52900045	-6514.94	2028.34	6823.38	287.29	320.11	0.55
52912046	0:15:32	C52900046	-6504.7	2007.44	6807.42	287.15	153.90	1.94
52912051	0:18:05	C52900051	-6437.14	2034.74	6751.07	287.54	68.00	0.48
52912054	0:20:19	C52900054	-6066.24	2018.43	6393.23	288.40	92.52	2.77
52912060	0:25:18	C52900060	-6323.95	2091.73	6660.91	288.30	285.88	0.90
52912061	0:26:05	C52900061	-6197.87	2068.57	6533.96	288.46	100.41	2.73
52912066	0:28:59	C52900066	-6558.88	2205.96	6919.91	288.59	290.84	2.22
52912075	0:34:28	C52900075	-6122.65	2116.26	6478.07	289.07	101.62	1.35
52912085	0:42:16	C52900085	-5999.55	2349.32	6443.13	291.38	27.84	0.56
52912086	0:42:30	C52900086	-6046.88	2375.85	6496.88	291.45	299.27	3.88
52912087	0:43:21	C52900087	-6433.43	2478.85	6894.47	291.07	284.92	7.84
52912089	0:46:10	C52900089	-6054.12	2464.21	6536.41	292.15	92.21	2.25
52912091	0:49:14	C52900091	-6252.32	2583.36	6765	292.45	301.01	1.26
52912093	0:50:10	C52900093	-5865.02	2484.37	6369.5	292.96	104.34	7.14
52912100	0:56:00	C52900100	-6003.46	2656.7	6565.03	293.87	321.22	0.63
52912103	0:58:45	C52900103	-5917.76	2708.71	6508.22	294.60	58.75	0.61
52912109	1:01:32	C52900109	-5891.86	2781.89	6515.59	295.28	19.49	0.46
52912114	1:05:50	C52900114	-5675.56	2805.28	6331	296.30	83.83	0.84
52912125	1:11:14	C52900125	-5735.17	2949.17	6449.01	297.21	337.50	0.48
52912126	1:11:58	C52900126	-5367.04	2877.86	6089.93	298.20	100.96	8.52
52912133	1:16:39	C52900133	-5221.28	2852.95	5949.88	298.65	99.70	0.53
52912140	1:22:04	C52900140	-5587.08	3118.84	6398.64	299.17	306.01	1.39
52912145	1:25:21	C52900145	-5546.15	3170.41	6388.38	299.75	38.44	0.33

28 May 1993 Seal Track #182

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
52811055	22:22:56	C52811055	-6772.41	544.02	6794.22	274.59		
52811078	22:37:27	C52811078	-6368.55	824.81	6421.74	277.38	55.19	0.56
52811116	23:04:50	C52811116	-6472.28	1152.05	6574.02	280.09	342.41	0.21
52811129	23:14:59	C52811129	-6492.36	1232.23	6608.26	280.75	345.94	0.14

28 May 1993 Seal Track #182

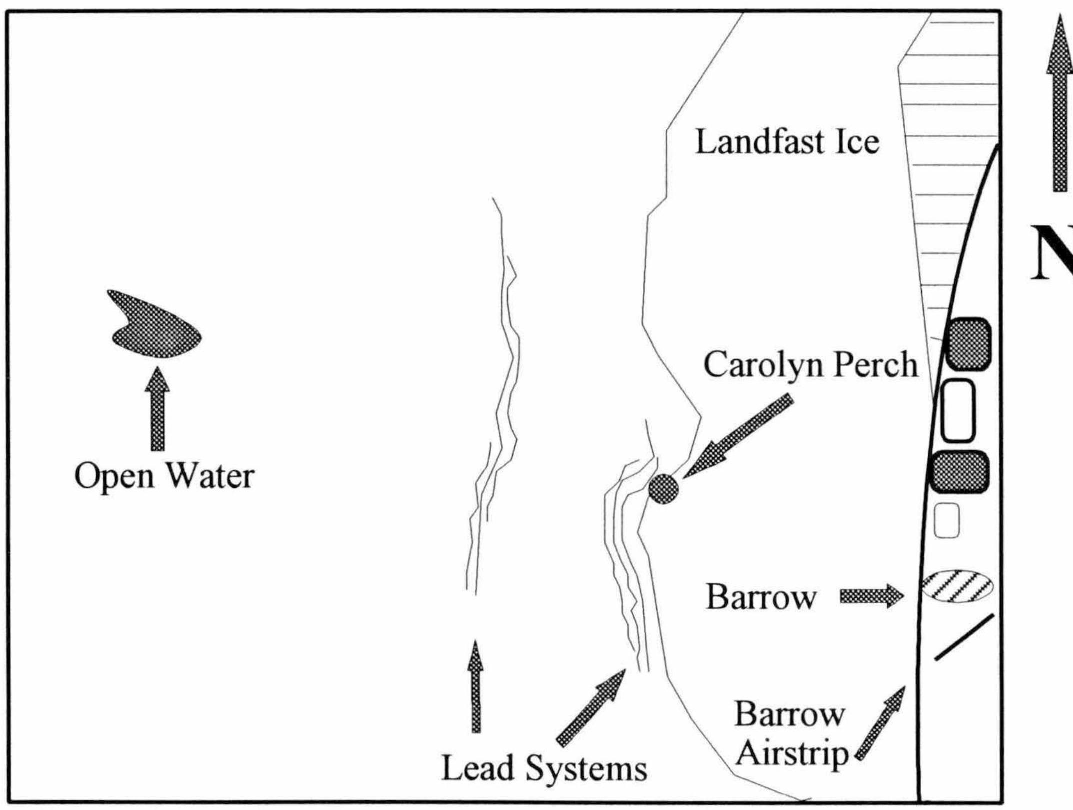
LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
52811136	23:17:48	C52811136	-6469.33	1258.51	6590.61	281.01	41.23	0.21
52811137	23:18:01	C52811137	-6975.38	1281.1	7092.05	280.41	272.56	38.97
52811154	23:26:59	C52811154	-6484.59	1306.69	6614.93	281.39	87.02	0.91
52811160	23:33:36	C52811160	-6121.4	1349.37	6268.36	282.43	83.30	0.92

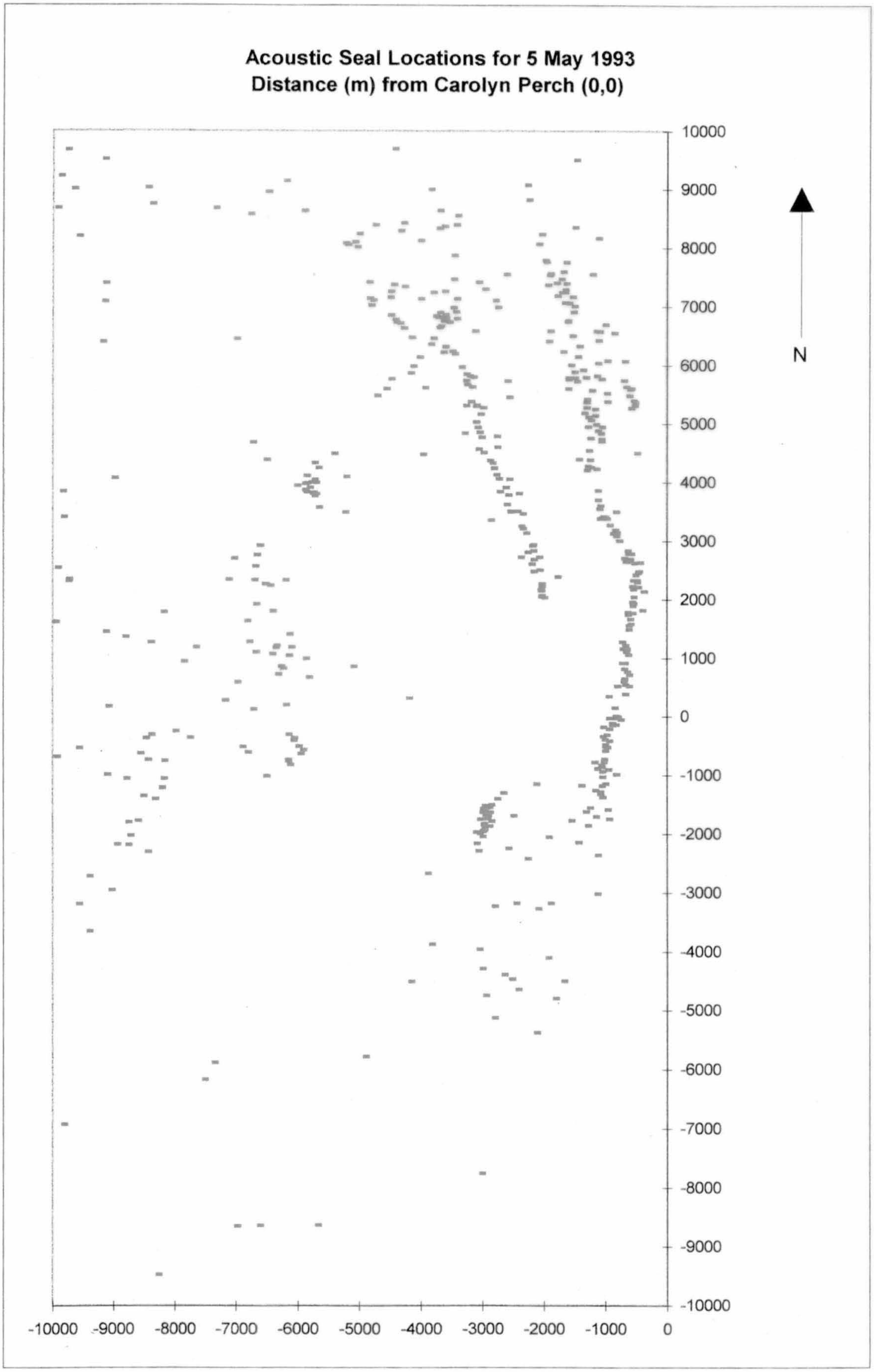
28 May 1993 Seal Track #150

LocID	Time	Track	XLoc	YLoc	Range (m)	Bearing	Seal Bearing	Swim Speed (m/sec)
52810032	20:25:46	C52810032	-8398.54	-908.90	8447.57	263.82		
52810066	20:59:42	C52810066	-8030.3	-455.54	8043.21	266.75	39.09	0.29
52810084	21:14:44	C52810084	-8315.07	-258.67	8319.09	268.22	304.66	0.38
52810087	21:17:54	C52810087	-8362.62	-227.63	8365.72	268.44	303.13	0.30
52810095	21:28:11	C52810095	-8294.31	-95.41	8294.86	269.34	27.32	0.24
52810098	21:31:56	C52810098	-7879	-60.46	7879.24	269.56	85.19	1.85
52811016	21:53:04	C52811016	-8208.14	217.82	8211.03	271.52	310.21	0.34
52811027	22:02:01	C52811027	-7803.09	308.03	7809.17	272.26	77.45	0.77
52811035	22:07:58	C52811035	-7846.31	429.24	7858.04	273.13	340.37	0.36
52811047	22:18:52	C52811047	-8083.02	576.82	8103.57	274.08	301.94	0.43

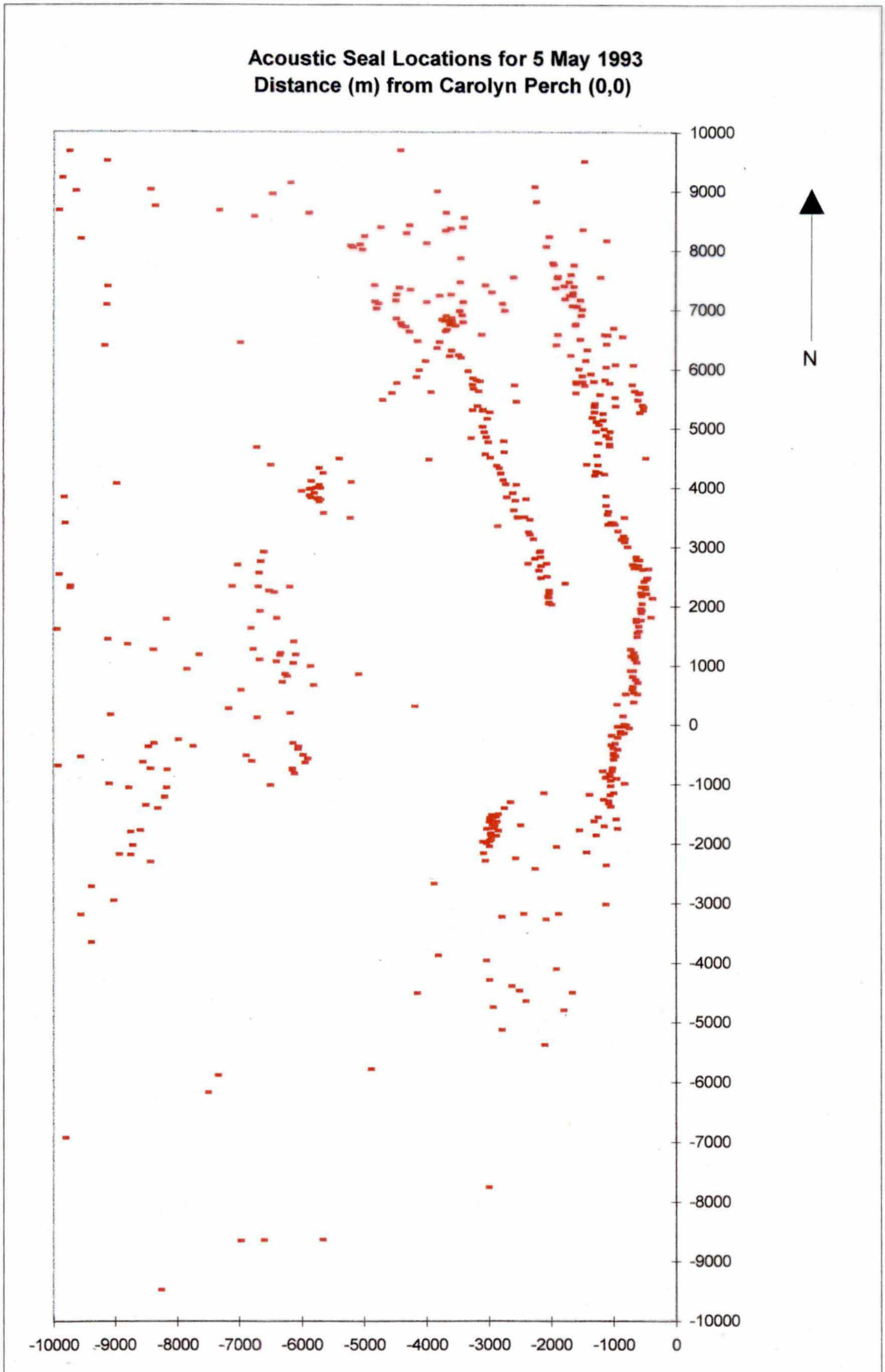
Appendix 3. 8 May 1993 Satellite Image and 5 May 1993 acoustic location overlay

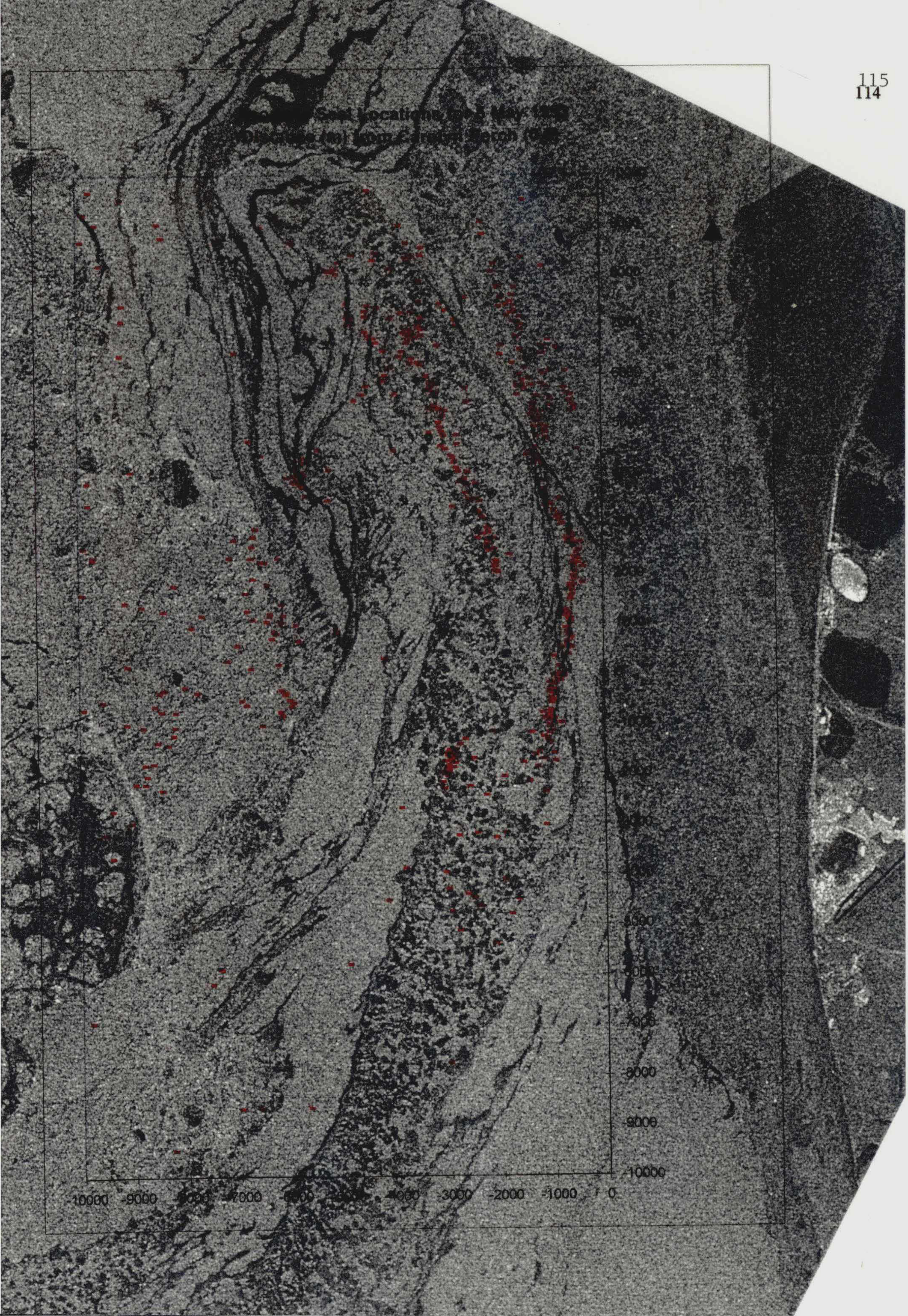
The figure below depicts various locations found on the satellite image of 8 May 1993. Barrow, Barrow airstrip and Carolyn Perch are indicated with arrows. The land-fast ice is shown here along the coastline. Open water and lead systems are the black areas to the west of the land-fast ice as shown here and on the satellite image. The lighter areas to the west of the land-fast ice on the satellite image consists of pack ice.





Acoustic Seal Locations for 5 May 1993
Distance (m) from Carolyn Perch (0,0)
N
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-10000
-10000 -9000 -8000 -7000 -6000 -5000 -4000 -3000 -2000 -1000 0


Acoustic Seal Locations for 5 May 1993
Distance (m) from Carolyn Perch (0,0)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-10000
-10000 -9000 -8000 -7000 -6000 -5000 -4000 -3000 -2000 -1000 0
N


Seal Locations
-10000
-9000
-8000
-9000
-7000
-4000
-3000
-2000
-1000
0
-10000
-8000
-7000